EFFECT OF MORTAR COMPOSITION ON WALL LEAKAGE

national lime association
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MASONRY MORTAR TECHNICAL NOTES # 5
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Effect of Mortar Composition on Wall Leakage

Moisture penetration can be a problem with any type of wall construction. In the case of masonry, which has served mankind universally and steadfastly for thousands of years, leakage is generally caused by one of three factors (or combination):

1) Improper design details
2) Poor workmanship
3) Use of improper (often incompatible) materials which bond together poorly.

Too often mason contractors receive the blame for leaky walls through so-called poor workmanship, but upon close investigations, the other factors often are the causes.

Because of a relatively high incidence of leaky wall problems during the mid-70's, a group of Chicago metropolitan area mason contractor-related organizations* sponsored a pioneering research study of water permeance in 1976-77 at the H.H. Holmes Testing Laboratories, Inc., Wheeling, Ill. Forty-eight composite masonry panels were built with varying mortar types (in triplicates) and subjected to artificially wind-driven rain for 72 hr. (ASTM Test Method E514-74). Mortar types studied included:

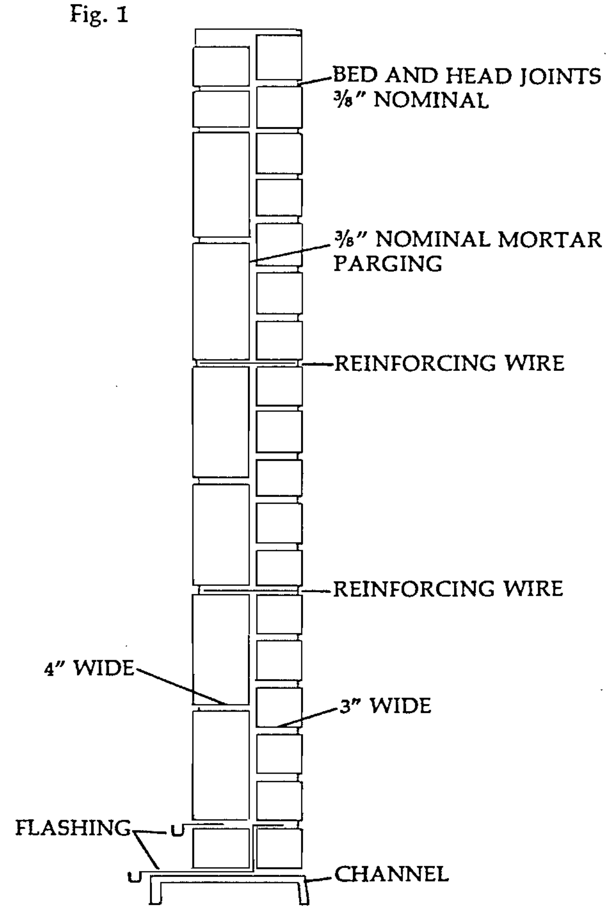
1) M,S,N and O portland cement-lime, and
2) M,S and N masonry cement, using four different brands of limestone-based masonry cement available in the Chicago area.

The principal conclusion of the study was that **walls constructed with portland cement-lime mortars were more resistant to water permeance than those constructed with masonry cement mortars.**[1]

This report deals with a *second* similar, but independent study carried out in April-June, 1977, also at the Holmes Laboratory; it was sponsored and financed by three National Lime Association members: Rockwell Lime Company, Manitowoc, Wis.; United States Gypsum Company, Chicago, Ill.; and Western Lime & Cement Company, Milwaukee, Wis. This study involved 30 test panels, built with (1) three portland cement-lime mortars—Type S (1 part portland cement, ½ part lime and 4½ parts sand), Type N (1:1:6), and Type O (1:2:9), and (2) one masonry cement mortar—Type N (one part masonry cement to 3 parts sand). As in the earlier study, four brands of masonry cement were included, but they were obtained from a wider geographical area, rather than only the Chicago area. In the first study the lime used was Type S (Special) hydrated lime; in the second, both Types S and SA (Special, Air-entraining) hydrates were included. As in the first study, three wall panels were built for each mortar type.

* See list of supporting groups in bibliography.

Fig. 1



Following the initial testing of the 30 panels, nine of them were cured outdoors for an additional six months, and then *re*tested for water permeance. Details of the lime-sponsored study and conclusions drawn follow.

Wall Construction The 30 test panels were approximately 50 in. long, 56 in. high, incorporating a 3-in. brick wythe, ⅜-in. mortar parging, and a nominal 4-in. concrete block wythe. Continuous galvanized joint reinforcement was placed at two courses and water trapping flashing at two locations (Fig. 1). The walls were built during two days by four experienced masons, using applicable procedures as outlined in BIA Tech Notes (Fig. 2-5). Workmanship was deemed "excellent," including full head and bed joints, tooled joints, etc. All of the test walls utilized lightweight concrete block and fired clay brick, selected from the same manufacturing lots; the physical dimensions and properties are given in Table 1. Each test wall was constructed with a single batch of mortar, which was mixed for 5 minutes in a commercial 9 cu. ft. mixer. One brand of portland cement and

Fig. 2—Experienced masons building the test wall panels.

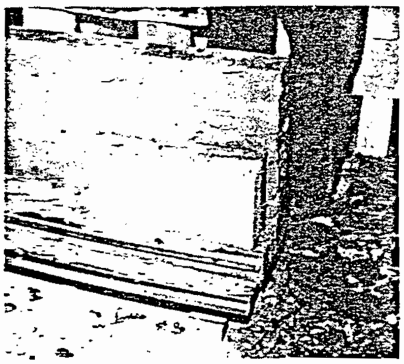


Fig. 3—Closeup showing two flashings on back side of panel.

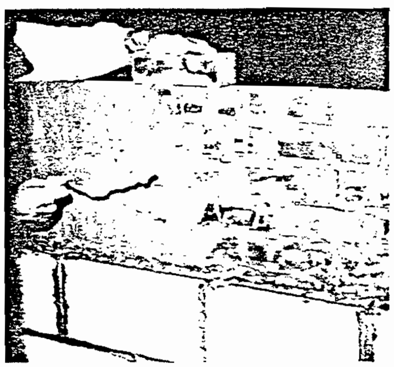


Fig. 4—Parging back of brick wythe with mortar.

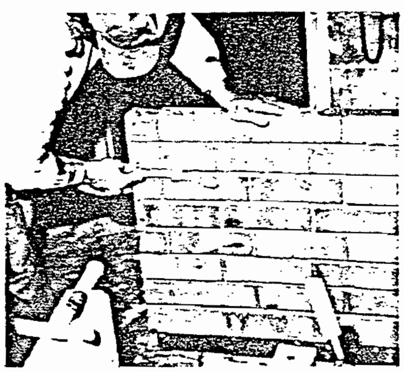


Fig. 5—Tooling joints on front of wall panel.

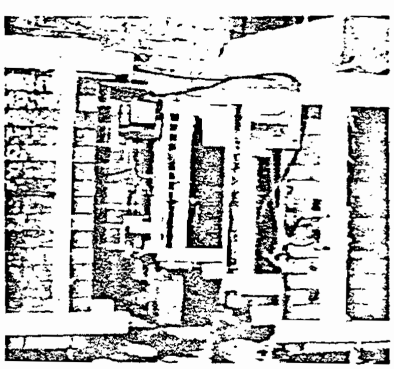


Fig. 6—Showing front view of several wall panels during actual water permeance testing; rain is simulated at a 5 in./hr. rate, with a 62.5 mph wind.

one type of sand were used for all batches, both materials being obtained locally. The sand gradation is given in Table 1.

Mortar samples for laboratory testing were taken from each batch, with the results summarized in Table 2. Additional mortar test data is presented in Table 3, but this is based on ASTM *laboratory* tests involving blended Ottawa sand. A study of the field mortar data in Table 2 indicates that the lime-cement mortars, including those made with air-entraining lime, had 28 days strengths well above the minimum requirement of the respective ASTM C270 mortar types. In general, the strengths of the Type N masonry cements were below the Type N cement-lime mortars, with one brand being slightly under the 750 psi Type N requirement. Average air contents were as follows: masonry cement mortars, 16-19%; cement-lime mortars (Type S lime), 4-5%; cement-lime mortars (Type SA lime), 13-17%. (The 17% measurement may have resulted from an experimental error, since air contents shown in Table 3, as determined with lab samples using Ottawa sand, were only 11-14%, which meets the 14% maximum air requirement of ASTM C207 for Type SA lime). A final observation from Table 2 is that water retention values for cement-lime mortars were generally higher than for masonry cement mortars: (83-91%) vs. (80-88%), respectively.

TABLE 1—Properties of Brick, Block, and Sand Used In Test Walls

BRICK

Nominal size—9½ in. x 3 in. x 2¾ in.
Cores—5
Absorption—24 hr.*—7.9%
Absorption—5 hr. boiling*—10.8%
Saturation coefficient*—73.6
Initial rate of absorption*—16.4 grams/min./sq. in.

* Avg. of 5 samples

CONCRETE BLOCK

Nominal size—4 in. x 8 in. x 16 in.
Cells—3
Unit weight (lb./cu. ft.)*—113.5
Absorption (by wt.)*—12.5%
Absorption (lb./cu. ft.)*—14.2
Moisture (by wt.)*—37.3%
Compressive strength* (gross area)—1526 psi
Compressive strength* (net area)—2385 psi

* Avg. of 5 samples

SAND

Sieve Size	*% Passing*	*ASTM Spec*
4	100	100%
8	100	95-100%
16	87.6	
30	63.5	
50	29.4	
100	14.8	25 max
200	5.6	10 max

SUMMARY—TABLE 2

Sample No.	Mortar* Type	ASTM C-91 Initial Flow	ASTM C-780 Air Content	ASTM C-91 Water Retention	ASTM C-780 Compressive Strength PSI 2x2 cubes	ASTM C-780 Compressive Strength PSI 3x6 cyls.	Permeance Rating
A-1	N(1-1-6)	104	4.5%	92.3%	1335	1704	F
A-2	N(1-1-6)	116	5.5%	91.4%	1438	1846	F
A-3	N(1-1-6)	116	4.5%	89.7%	1487	1761	E
A-4	N-A(1-1-6)	120	19.0%	88.3%	1272	1268	P
A-5	N-A(1-1-6)	97	18.0%	92.8%	1412	1308	P
A-6	N-A(1-1-6)	100	13.5%	92.0%	1405	1345	E
A-7	O-A(1-2-9)	108	14.5%	88.9%	462	411	F
A-8	O-A(1-2-9)	120	11.0%	90.0%	570	482	F
A-9	O-A(1-2-9)	104	14.1%	94.2%	577	378	F
A-10	O(1-2-9)	114	4.9%	91.2%	712	628	F
A-11	O(1-2-9)	116	5.0%	87.9%	545	538	F
A-12	O(1-2-9)	120	4.0%	90.0%	577	548	F
A-13	S-A(2-1-9)	132	15.0%	89.4%	2298	2181	P
A-14	S-A(2-1-9)	142	13.7%	78.9%	1948	1709	P
A-15	S-A(2-1-9)	144	11.0%	80.6%	2143	1889	P
A-16	S(2-1-9)	124	3.3%	83.9%	2100	2559	F
A-17	S(2-1-9)	132	5.1%	87.9%	1797	1879	F
A-18	S(2-1-9)	128	2.4%	90.6%	2847	2573	F
A-19	N(Masonry A)	120	17.8%	90.0%	765	812	F
A-20	N(Masonry A)	144	14.0%	75.7%	978	1034	F
A-21	N(Masonry A)	112	17.7%	82.1%	810	793	P
A-22	N(Masonry B)	102	18.1%	92.2%	963	855	P
A-23	N(Masonry B)	100	20.0%	86.0%	1073	973	P
A-24	N(Masonry B)	106	19.8%	79.2%	1013	642	P
A-25	N(Masonry C)	116	15.1%	86.2%	1225	902	P
A-26	N(Masonry C)	108	17.0%	81.5%	1453	1190	P
A-27	N(Masonry C)	122	14.8%	95.2%	1353	1043	P
A-28	N(Masonry D)	117	17.3%	86.3%	713	656	P
A-29	N(Masonry D)	112	18.3%	75.0%	722	751	P
A-30	N(Masonry D)	132	15.0%	78.8%	570	779	P

* In samples A-4-9 and A-13-15, the "A" designation after the mortar type refers to use of type SA (air entraining lime) In samples A19-30, the mortar proportion was 2 parts masonry cement to 6 parts sand

SUMMARY—TABLE 3

Sample No.	Mortar* Type	ASTM C-91 Initial Flow	ASTM C-91 Air Content	ASTM C-91 Water Retention	ASTM C-109 Compressive Strength PSI 7 Day	ASTM C-109 Compressive Strength PSI 28 Day
1.	N(1-1-6)	114	5.1%	91.2%	1275	1720
2.	NA(1-1-6)	112	13.8%	90.2%	1098	1340
3.	SA(2-1-9)	110	11.4%	90.9%	2555	2961
4.	S(2-1-9)	110	4.8%	89.1%	2871	3686
5.	O(1-2-9)	108	3.9%	88.0%	540	730
6.	OA(1-2-9)	112	12.6%	87.5%	318	438

* "A" designation after mortar type indicates use of air entraining lime

Wall Test Procedure Test walls were allowed to cure together in laboratory air for a minimum period of 28 days prior to testing. A test chamber was then placed on the front of each wall panel, (Fig. 6), and the wall subjected to a 24 hr. preconditioning period, a 24 hr. (minimum) drying period, and the 72 hr. testing period. During the preconditioning and test periods, artificially wind-driven water was applied continuously to the brick face, simulating a 5 in./hr. rainfall and near-hurricane force 62.5 mph wind. Extent of damp wall area and volume of water passing through brick and block wythes were determined at 24, 48, and 72 hrs. In addition, time of first appearance of both dampness and visible water on the backs of the wall panels were recorded.

Fig. 7—TOTAL WATER PERMEANCE (in 72 Hr.)

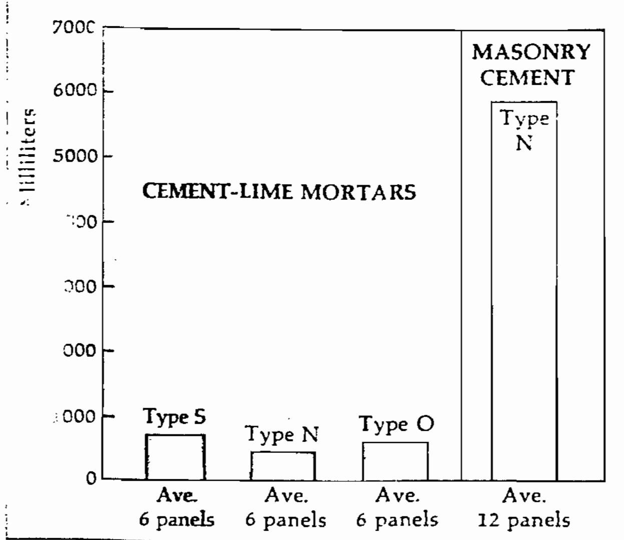
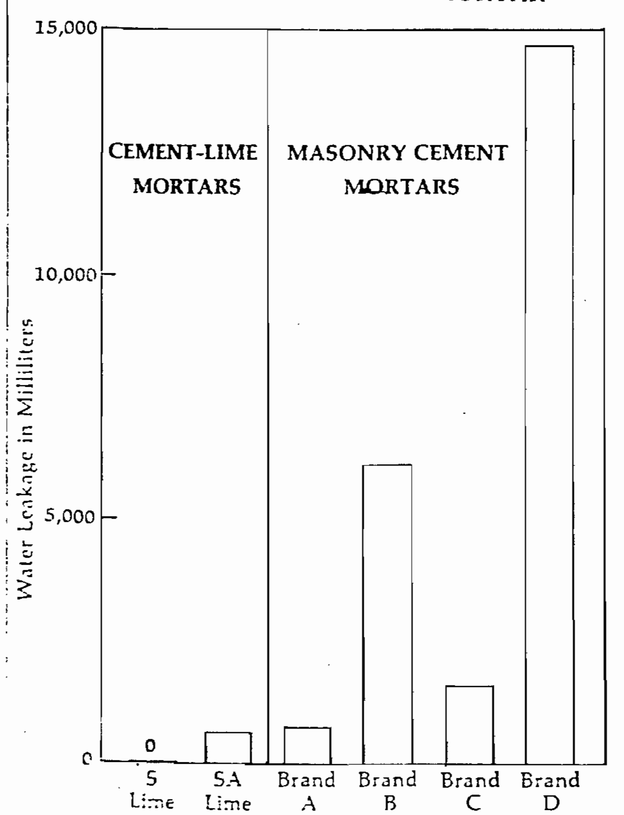


Fig. 8—TOTAL WATER PERMEANCE (in 72 Hr.) OF PANELS MADE WITH TYPE N MORTAR*



* Each bar represents average of three panels

Test Findings

Water Leakage Fig. 7 presents data on average total water leakage in 72 hr. (collected from both flashings) for the 30 test panels. It is readily apparent that panels built with portland cement-lime mortar resisted water penetration to a much greater degree than the masonry cement panels. Ten of the cement-lime panels (55%) exhibited no or negligible leakage, in contrast to only two (17%) of the masonry cement panels.

The poorest masonry cement panel had a total leakage of 36,200 ml., the poorest cement-lime panel had 2055 ml., the latter occurring in the first 24 hr. If the poorest masonry cement panel was thrown out (as an outlier), the average leakage of the remaining 11 panels would still be high—3130 ml., compared to 570 ml. for the 18 cement-lime panels. Note that the panels made with Type N cement-lime mortar were slightly better than the panels made with Types S or O, although the differences weren't great.

This latter finding was essentially the same reported in the earlier study by Brown,[1] although for the masonry cements tested, the Type S mortars were slightly superior to Type M, and significantly superior to Type N in resisting water permeance. The poorer performance of the lower strength Type N masonry cements was undoubtedly due to their containing less cementing material.

In order to compare equivalent mortars, Fig. 8 shows average total water leakage of the 18 panels made with *Type N mortar*—12 masonry cement and six cement-lime. Three of the latter contained Type S (non-air-entraining lime) and three Type SA (air-entraining lime). Again, the poorer performance of the masonry cement panels is clearly evident. Also note that the use of Type S lime led to somewhat less leakage than when Type SA lime was used. This also occurred with the panels made with Type S (1:½:4½) mortar, but not with the panels made with Type O (1:2:9) mortar. Of the nine panels containing Type SA lime, three exhibited zero or negligible leakage, whereas seven of the nine panels made with Type S lime had zero or negligible leakage.

Rate of Leakage Fig. 9 presents data on average time for water penetration for the 30 test panels, both in terms of time for first dampness and first visible water on the backs of the panels. The latter is especially significant since it denotes actual leakage. It is readily apparent that water passage was much faster through the masonry cement panels than through the cement-lime panels. Dampness first appeared in an average of about 1 hr. for the 12 masonry cement panels, contrasted to 2.2 hr. for the 18 cement-lime panels, with eight of the masonry cement panels (67%) showing dampness within 1 hr., compared to only five of the cement-lime panels (28%). Note that for the cement-lime panels, increase in lime content increased the time for first dampness to appear.

Visible water (actual leakage) first appeared on the masonry cement panels in an average of 2.2 hrs., contrasted to 10.2 hr. for the cement-lime panels. Two of the masonry cement panels showed visible water within 1 hr., against none of the cement-lime panels.

Again to compare like mortars, Fig. 10 shows time for first water penetration for each of the 18 panels made with Type N mortar. Note the better performance of the cement-lime panels, with two showing no visible water for 31 and 50 hrs., respectively. Note, too, that use of Type SA (air-entraining) lime led to faster leakage than where Type S (non-air-entraining) lime was used. This was also true of the Type S mortar panels; however, with the Type O panels, those made with Type SA lime showed slower water passage, duplicating the better performance shown earlier in terms of total water leakage.

Fig. 9—TIME FOR WATER PENETRATION

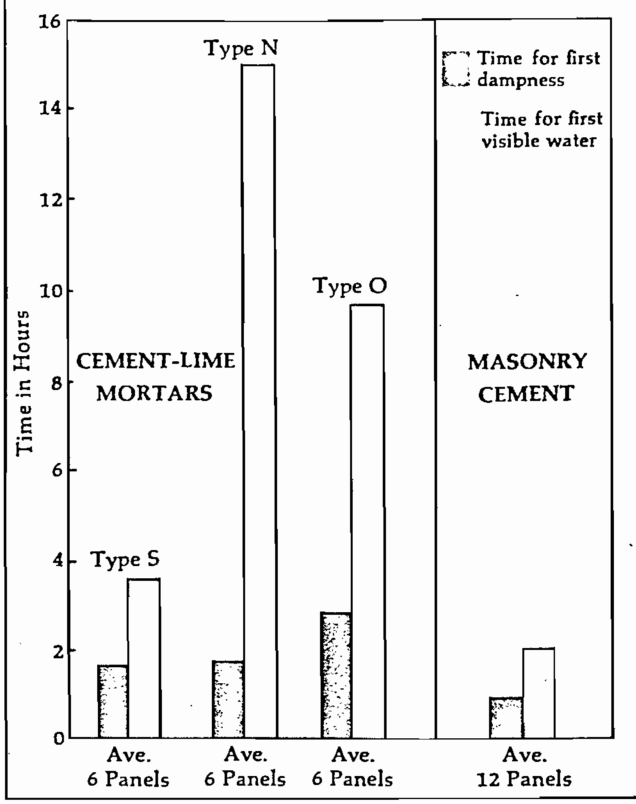
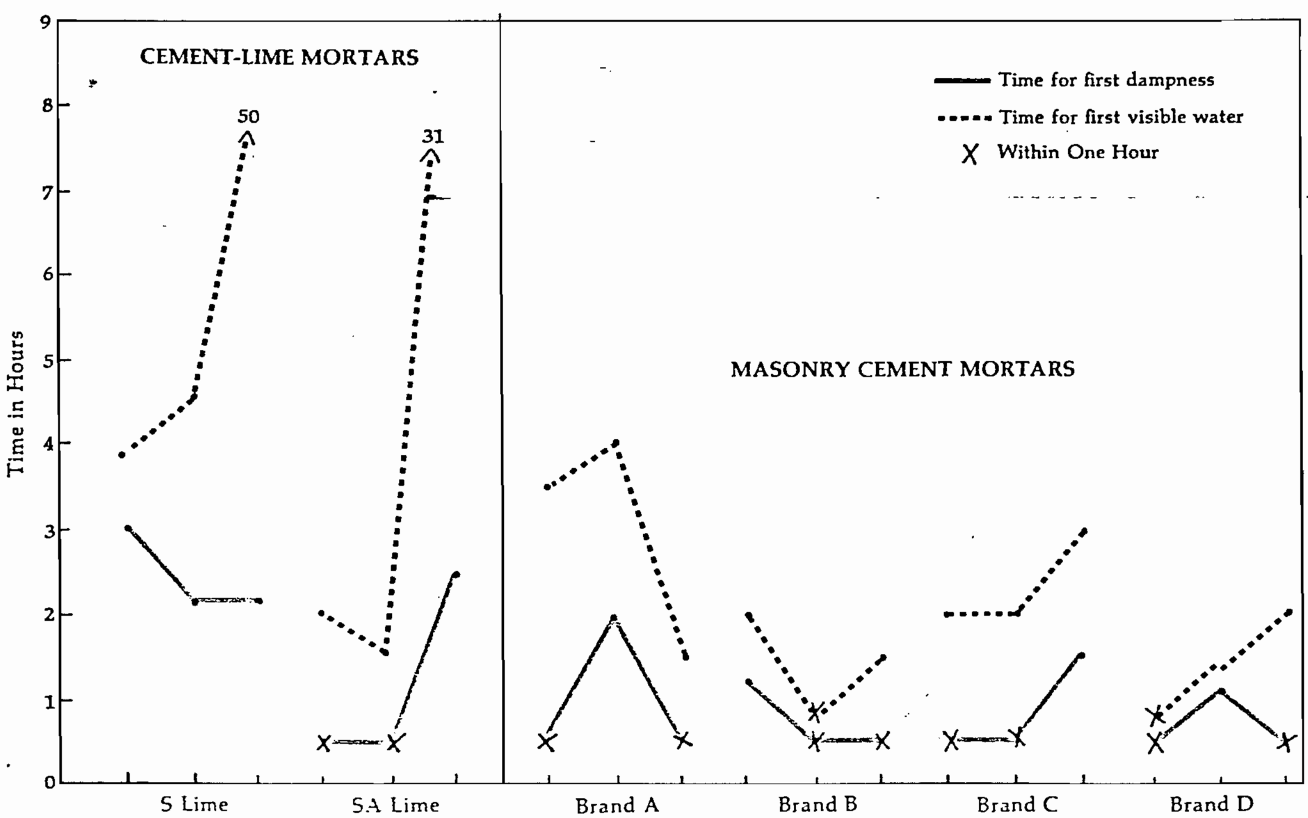


Fig. 10—TIME FOR WATER PENETRATION (TYPE N MORTARS)*



* *Each point represents one wall panel.*

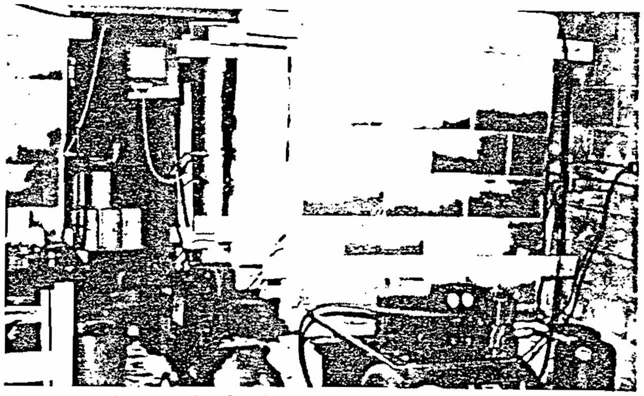


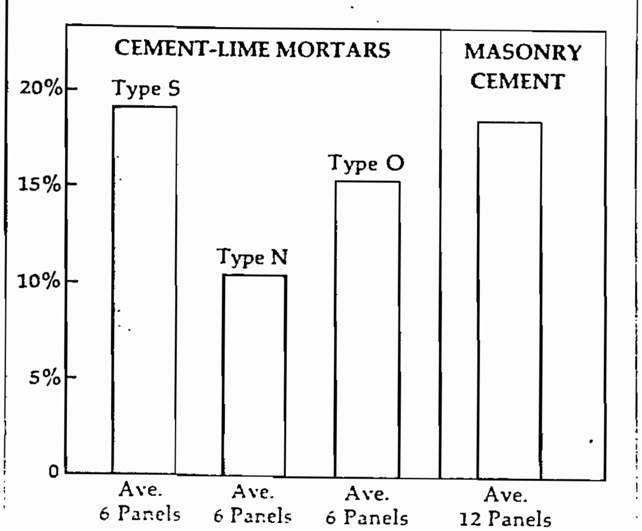
Fig. 11—Showing back of wall panels during water permeance testing; note variation in extent of damp area.

Extent of Damp Area Fig. 11 shows the varying extent of dampness of the backs of the wall panels during testing. In terms of percent of damp area after 72 hr., again the cement-lime panels performed better than the masonry cement panels, although the differences between the two types were not as great as with other leakage parameters; the 18 cement-lime panels averaged 15.1% dampness, and the 12 masonry cement panels, 18.7% (the range was 0.6-43% for individual panels). Fig. 12 shows that Type N cement-lime panels performed the best (10.6% average dampness), followed by the Type O panels (15.2%).

In considering only the 18 Type N mortar panels (Fig. 13), note that the cement-lime panels made with Type S lime performed slightly better than those made with Type SA lime, and that the latter were considerably better than each of the four masonry cements tested.

One final note: three of the 30 panels exhibited less than 5% dampness, all made with cement-lime mortar. The best wall in terms of dampness (0.6%) was a Type O mortar, made with Type SA (air-entraining) lime.

Fig. 12—PERCENT OF DAMP AREA (in 72 Hr.)



Wall Ratings In the ASTM E 514 test, walls are rated as follows, going from best (E) to worst (L):

Class E No water visible on back of wall above flashing at the end of 1 day. Not more than 25% of wall area above flashing damp at the end of 3 days. No leaks through wall at the end of 1 day.

Class G No water visible on back of wall above flashing at the end of 1 day. Less than 50% of wall area above flashing damp at the end of 1 day. No leaks through wall at the end of 1 day.

Class F Water visible on back of wall above flashing in more than 3 hrs. and less than 24 hrs. Rate of leakage less than 0.264 gal. (1 litre)/hr. at the end of 1 day.

Class P Water visible on back of wall above flashing in 3 hrs. or less and rate of leakage less than 1.32 gal. (5 litre)/hr. at the end of 1 day. Water visible on back of wall above flashing in more than 3 hrs. and less than 24 hrs. and rate of leakage more than 0.264 gal. (1 litre) and less than 1.32 gal. (5 litres)/hr. at the end of 1 day.

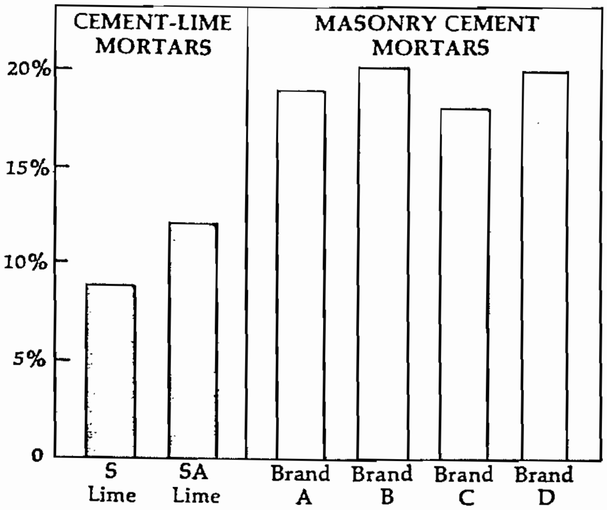
Class L Rate of leakage through wall equal to or greater than 1.32 gal. (5 litres)/hr. at the end of 1 day.

Tables 2 and 4 give the performance ratings of the 30 test panels. Judging from findings reported earlier, it is no surprise that the panels made with cement-lime mortar received much higher ratings than those made with masonry cement. Note from Table 4 that two (11%) of the cement-lime panels were rated "excellent," 11 (61%) "fair," and five (28%) "poor," whereas only two (17%) of the masonry cement panels were "fair" and ten (83%) "poor." Considering the cement-lime panels only, those made with Type S lime received higher ratings than those made with Type SA (one "excellent" and eight "fair," *vs.* one "excellent," three "fair," and five "poor," respectively).

TABLE 4—Permeance Ratings of Test Panels, by Mortar Types

Mortar Type	E	G	F	P	L
Portland Cement-Lime					
Type S	–	–	3	3	–
Type N	2	–	2	2	–
Type O	–	–	6	–	–
Masonry Cement					
Brand A	–	–	2	1	–
Brand B	–	–	–	3	–
Brand C	–	–	–	3	–
Brand D	–	–	–	3	–

Fig. 13—PERCENT OF DAMP AREA (in 72 Hr.) OF PANELS MADE WITH TYPE N MORTAR*



** Each bar represents average of three panels.*

Six Months Re-test Nine of the test panels (six cement-lime and three masonry cement) were stored outdoors for six months (including the summer months) and retested for water permeance. Table 5 shows the results.

Note that four of the cement-lime panels improved (one by jumping three grades) and two remained the same (one P and one E); whereas only one masory cement panel improved (by two grades), one remained the same (P), and one went down one grade (F to P). It is interesting to note that the one masonry cement that improved was the only one of the four masonry cement tested that contained lime (Type S hydrate). With one exception, all of the cement-lime panels remained dry for a longer time; average time for first dampness went from 2.1 hr. to 10 hr., and for first visible moisture, from 12 hr. to 43 hr. Total leakage was reduced in two of the cement-lime panels, two remained the same (0 leakage), and two increased. The one masonry cement panel that improved in rating showed less leakage and increased time for first dampness and visible moisture; the other two leaked faster.

Of course, the findings from retesting after six months cannot be considered as valid as the original 28 day study, since single tests (one duplicate) were performed, not triplicate tests as in the first study. However, there is a definite indication that the additional curing led to an increase in tightening of the walls made with mortars containing Types S or SA lime.

British Wall Permeance Tests

The Mortar Producers' Association, Warwickshire, England, sponsored a series of water permeance tests in 1976 at the Birmingham Polytechnic's Dept. of Construction and Surveying, utilizing the British BS 4315 Pt. 2, (1970) test method. [2,3] Fig. 14 shows the rain penetration machine and control panel. Three mortar types (1:1:6 cement:lime:sand, 1:4½ masonry cement:sand, and 1:6 air-entrained cement:sand) and five brick types were used. Performance was determined by (1) percent of area wetted on inside of panel, and (2) moisture absorbed, as determined by increased weight of panel.

In three out of the five series of tests, walls built with lime-based mortar showed greater resistance to water penetration than walls built with the two other mortars. In still another series, less water was absorbed by walls built with lime-based mortar in four out of five tests.

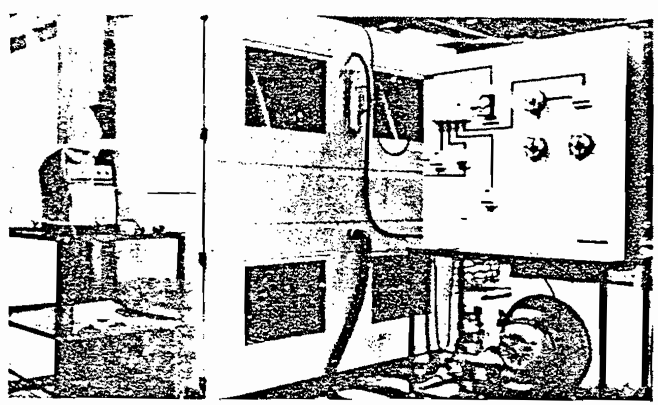


Fig. 14—British rain penetration machine showing control panel

TABLE 5—Permeance Ratings After Six Months Outdoor Curing

Panel No.	*Mortar Type*	*Lime Type*	*Original Rating*	*6 Mos. Rating*	*Change*
A-18	(PC-L)-S	S	F	G	+1
A-13	(PC-L)-S	SA	P	P	same
A-4	(PC-L)-N	SA	P	E	+3
A-6	(PC-L)-N	SA	E	E	same
A-12	(PC-L)-O	S	F	G	+1
A-7	(PC-L)-O	SA	F	G	+1
A-19	(MC)-Brand A	—	F	P	−1
A-22	(MC)-Brand B	—	P	G	+2
A-29	(MC)-Brand D	—	P	P	same

Note: PC-L refers to portland cement-lime, and MC to masonry cement.

Fig. 15 shows the performance of walls built with clay bricks laid "frogs down," in terms of percent of wall wetted; note superior performance of the 1:1:6 mortar. This improved performance was attributed to the better workability of the lime-based mortar, enabling better filling of the frogs.

Fig. 15—RAIN PENETRATION OF CLAY BRICK WALLS WITH BRICKS LAID FROGS DOWN, USING THREE MORTAR TYPES

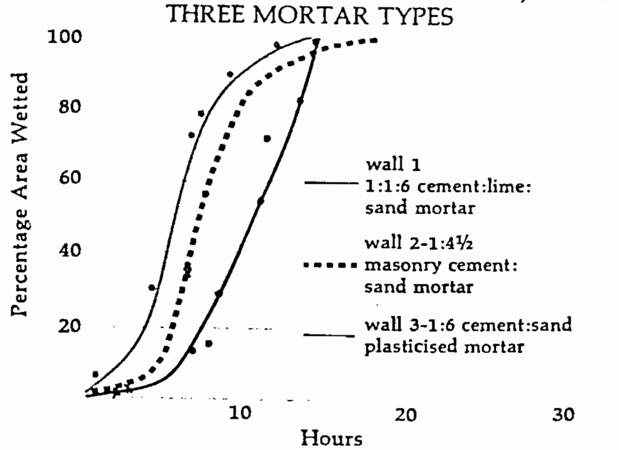


Fig. 16, dealing with walls made with clay brick "frogs up," shows the better performance of the 1:1:6 mortar, as indicated by less gain in weight due to less water absorption.

The British study also included a series on the effect of curing on water permeance.[4] Fig. 17 shows one of the tests involving 1:1:6 mortar and calcium silicate brick. Note that the results parallel the Holmes six months *re*testing study described earlier, namely the improved resistance to water penetration with aging.

Fig. 16

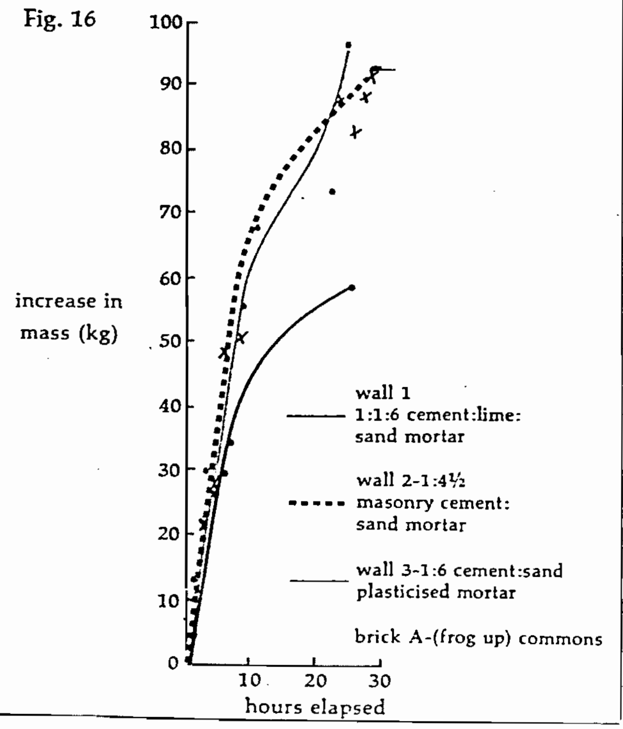
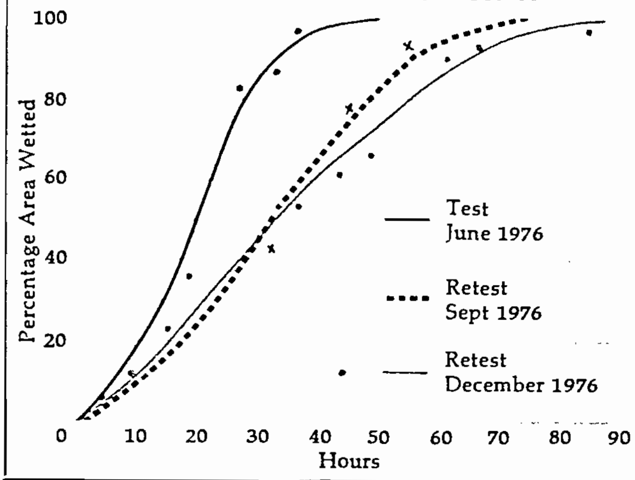


Fig. 17—EFFECT OF STORAGE ON RAIN PENETRATION OF CALCIUM SILICATE BRICK PANELS MADE WITH 1:1:6 MORTAR



Conclusions and Explanations

The National Lime Association member study of the 30 composite masonry test panels clearly points to the superiority of the portland cement-lime mortars over the masonry cement mortars tested in terms of reducing water permeance. Improved performance was shown by several parameters:

- Reduced water leakage, by a magnitude of ten times.
- Longer time for first dampness to appear (more than twice the time).
- Longer time for first visible water to appear (by a magnitude of five times.)
- Lower percentage of damp area on backs of panels.
- Higher water permeance ratings, as a consequence of the above.
- Greater resistance to water penetration after curing an additional six months.

An explanation of the better performance of the lime-based mortars over the masonry cement mortars in terms of reduced water permeance centers around lime's higher plasticity and water retention, its greater fineness and stickiness, and its lower air content.[5] These factors contribute to an excellent extent of bond between mortar and masonry unit. Lime also possesses the capability of reconstituting itself through carbonation (referred to as autogenous healing)[6], wherein carbon dioxide from the atmosphere combines with the lime to form new calcium carbonate. The minute crystals thereby formed tend to plug the voids or any hairline cracks that may have developed, thereby creating a more impervious mortar and an even tighter bond between mortar and masonry unit. This self-healing aspect of lime in mortar helps explain the increased moisture resistance noted after the six months of outdoor curing, in both the Holmes and the British studies.

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Appendix

What is lime?

The term "lime," in spite of being used broadly and loosely, *only* embraces burned lime products—quicklime and hydrated lime—and *not* pulverized limestone, which is used in many masonry cements. Limestone is a *carbonate* form of calcium or calcium-magnesium—a sedimentary rock, possessing completely different properties than lime, which is an *oxide* or a *hydroxide* of calcium or calcium-magnesium. Lime is a manufactured product (basic chemical), made from limestone by calcination at high temperature (about 2400° F.) in kilns. The resulting product, quicklime (unslaked lime), is used as a mortar material after slaking into putty—or is converted to hydrated lime. The hydration process disintegrates the lump, pebble, or granules of quicklime into an extremely fine, white powder by adding a controlled amount of water, enough to satisfy its chemical affinity.

Limestone has no cementing value, whereas lime contributes some strength to mortar by recarbonation, i.e., absorbing carbon dioxide from the atmosphere and reverting to its original carbonate form.

Hydrated limes are divided into four types, as described in ASTM Specification C 207:

Type N—Normal hydrated lime
Type S—Special hydrated lime
Type NA—Normal air-entraining hydrated lime
Type SA—Special air-entraining hydrated lime

Types S and SA are differentiated from Types N and NA principally by their ability to develop high early plasticity, higher water retentivity, and by their limitation on unhydrated oxide content. The maximum air content of cement-lime mortar made with Types NA or SA lime shall be 14%; with Types N or S lime, 7%.

Lime putty, derived from slaking quicklime, generally possesses most of the Type S properties.