5 Evidence from previous studies

In response to problems experienced with water penetration of masonry walls in the USA, a number of studies (Borchelt et al., 1999; Brown, 1978; Matthys, 1988; National Lime Association, 1979; Schuller et al., 1998) were independently carried out on the performance of mortars with respect to penetration of walls by driving rain. These studies evaluated the effects of different mortar mixes on water permeance of masonry. All these studies showed that walls built with cement-lime mortars (containing Type S hydrated lime and meeting the specifications of ASTM C 270) were significantly more resistant to water penetration than walls built with masonry cements.

The “Permeance test method” (Appendix 2: ASTM method E 514), used in the studies reported below is a severe test, examining the impact of near-hurricane wind and rainfall conditions on a masonry panel. Water is sprayed against the masonry, inside an environmental chamber, at a rate representing rainfall of 5 inches per hour. Air pressure is maintained to represent a wind of 62.5 mph. The time of first appearance of dampness and visible water on the rear of the test panel is noted. The rear of the test panel is examined after 24, 48, and 72 hours of exposure to determine the extent of water penetration. At the base of the panel, a metal flashing trough collects and measures any water that has penetrated the test wall.

Table 5.1 Summary of testing conditions for studies mentioned above.
(Ref. National Lime Association Building Lime Group, October 2000. www.lime.org/)

		Research Study				
Variable	**ASTM E 514 Procedure**	**Chicago Contractors Holmes Laboratory**	**USG/ Rockwell/ Western Holmes Lab**	**NLA Matthys Brick**	**BIA/PCA/ NLA Nelson**	**Chemical Lime Atkinson, Nolan**
Year (ref)		1976-77[ii]	1977 [iii]	1988 [iv]	1998-99 [v]	1999 [vi]
Moist chamber size (ft^2)	12	12	12	12	12	12
Wall panel size	56" x 72"	49" x 52"	50" x 56"	40" x 53"	40" X 53"	40" x 53"
Panel wythes (type)	Single (Job[2])	Two[1] (4" clay & 4" cement)	Two[1] (3" clay & 4" cement)	Single (4" clay)	Single (4" clay)	Single (4" cement)
Mortar types (ASTM C 270 Proportion Specification)	Job[2]	M,S,N,O + 3 masonry cements[3]	S,N,O + 4 masonry cements[3]	S,N,O + 4 masonry cements[3]	N + 1 masonry cement[3]	S (4 lime products) + 4 lime replacements
Cure time (days)	14	28[4]	28[4]	28[4]	28[4]	28[4]
Cure conditions	Lab plastic[6]	Lab NR[7]	Lab plastic[6]	Outdoors[5] plastic[6]	Lab plastic[6]	Lab plastic[6]
Pretest drying (hr)	4	24	24	NR[7]	NR[7]	NR[7]
Pretest (optional)	28 days	None	6 months	NR[7]	NR[7]	NR[7]
Replications	3	3	3	3	3	3
Tooling	Job[2]	Concave	Concave	Concave	Concave	Concave
Test time (min hrs)	4	72	72	4	72	4
Sand	Job[2]	Job[2]	Job[2]	Job[2]	Job[2]	Job[2]

1. Double brick wythes were used to simulate contemporary construction practice.
2. "Job" refers to materials representative of current construction practice.
3. Commercial one bag dry mortar mixes.
4. 28 days is a standard curing time for many ASTM mortar test procedures.
5. Panels were built, cured, and tested under ambient conditions to duplicate conditions under which actual masonry walls are constructed.
6. Panels were wrapped in plastic to maintain high humidity and consistency during curing.
7. "NR" indicates no data given for this condition in published reports.

5.1 Comparisons of masonry cement to cement-lime mortars

Masonry cement and mortar cements are proprietary mixes consisting of cement, limestone and additives to enhance plasticity. Although they may contain hydrated lime, they are dominantly Portland cement, producing a high strength, rapid setting mortar. Masonry mortar mixtures known as cement-lime, as used in these USA-based studies, are made of cement and lime as defined in ASTM Standard C 270 (Mortars for Unit Masonry)[*].

[*] *Standard Specification for Mortar for Unit Masonry (ASTM C 270), American Society for Testing Materials, Philadelphia, PA.*

Lime was historically used as the primary binding material in combination with sand. Lime mortars harden by carbonation, absorbing carbon dioxide from the atmosphere to form calcium carbonate. They are relatively soft and porous, and have little change in volume during temperature fluctuations. Lime mortars are slightly water soluble, allowing them to heal any hairline cracks that develop.

By contrast, mortars made with Portland cement and sand are very hard and impermeable. Setting is rapid and does not require carbonation. Portland cement mortars shrink on setting and have relatively large volume changes during temperature fluctuations. The addition of Portland cement to an essentially lime mortar can provide some early strength and speed setting.

Cement-lime mortar contains the following in various proportions:

1. Hydrated lime: Meets ASTM C 207 Type S or SA.
2a. Portland cement: Meets ASTM C 150 Types I, IA, II, IIA, III, or IIIA.
or
2b Blended hydraulic cement: Meets ASTM C 595 Types IS, IS-A, IP, IP-A, I(PM) or I(PM)-A.
3. Sand: Meets ASTM C 144.

Hydrated lime types

There are 2 basic types of hydrated limes. Special, or "S"-types, are able to develop high early plasticity, have higher water retention and have a limitation on their content of unhydrated lime:

Type N: Normal hydrated lime
Type S: Special hydrated lime

In addition, "A" types have a higher proportion of minute voids as they include an air-entraining agent in the mortar mix (maximum air entrainment of 14% compared to 7% for non-A types):

Type NA: Normal air-entraining hydrated lime
Type SA: Special air-entraining hydrated lime

Mortar types

The ASTM Standard C 270 (Mortars for Unit Masonry) provides the basis for four different mortar types (shown as Cement : Hydrated lime : Sand by volume) depending on the strength of mortar required (there is also a fifth, "K" type). The mortar type must be determined based on the strength required for the application, as shown below in Table 5.2.

Table 5.2 Recommended (ASTM Standard C 270) mortar types for applications.

Application	Recommended mortar type
Exterior, above grade, load-bearing wall	N (or S or M)
Exterior, above grade, non-load-bearing wall	O (or N or S)
Exterior, above grade, parapet wall	N (or S)
Exterior, at- or below-grade	S (or M or N)
Interior, load-bearing wall	N (or S or M)
Interior, non-bearing partition	O (or N)

Table 5.3 ASTM C 270 Proportion and property[a] specifications. Portland cement/lime mortars should be specified by either the property or the proportion specification but not both. When neither the proportion or property specifications are specified, the proportion specifications govern.

	Proportion specifications			Property specifications		
Mortar type	Proportions by volume		Aggregate ratio - measured in damp, loose conditions	Av. compressive strength at 28 days (psi)	Water retention (%)	Air content max. %
	Cement	Hydrated lime				
M	1	¼	Not less than 2 ¼ and not more than 3 times the sum of the separate volumes of cementitious materials	2,800	75	12
S	1	Over ¼ to ½		1,500	75	12
N	1	Over ½ to 1 ¼		750	75	14[b]
O	1	Over 1 ¼ to 2 ½		350	75	14 [b]
K	1	3		75		

A - Laboratory prepared mortar only
B - When structural reinforcement is incorporated in cement-lime mortar, the maximum air content shall be 12%.

Table 5.4 summarises the test data obtained. The information is shown graphically in Figures 5.1 to 5.4. It is clear that significant differences exist between cement-lime and masonry cement mortars:

Table 5.4 Summary of water permeance test data. Data are averages from a number of mixes in each category. (Ref. National Lime Association Building Lime Group, October 2000. www.lime.org/)

Tests performed	**Chicago Contractors Holmes Laboratory (CCHL)**		**USG/ Rockwell/ Western Lime Holmes Lab (USG)**		**NLA Matthys Brick (NLA)**		**BIA/PCA/ NLA Nelson (BIA)**	
	CL	**MC**	**CL**	**MC**	**CL**	**MC**	**CL**	**MC**
First dampness (hr)	2.9	2.0	2.7	2.0	2.3	1.0	0.25	0.1
First visible water (hr)	11.6	3.8	12.1	2.1	9.7	2.0	0.50	0.1
% dampness (4 hr)	16.8	28.4	13.0	18.7	15.1	18.7	90.0	95.0
Total water (72 hr)	1,744	103,471	3,529	70,650	2,550	6,000	1,170	18,000
Number of panels	4	31	5	11	18	12	3	3
Leakage/panel (ml)	436	3,338	706	6,423	142	500	234	3,600

CL = cement-lime MC = masonry cement

Mosquera et al. (2002) investigated the relationship between some properties of mortars (Table 5.5) and their potential performance on granite buildings. As would be expected, increasing porosity generally led to decreased mortar strength and increased vapour permeability (Table 5.6). The authors concluded that a 9:1 sand:cement mix would have the most suitable properties for repointing granite buildings. This was because it had similar mechanical properties to a lime:cement mix, while having lower free calcium (which could form gypsum). However, its vapour permeability was significantly lower than that of a lime:cement mix. The performance of mortar mixes described in this paper were not tested on buildings or test panels.

The 9:1 sand:cement mix favoured by Mosquera et al (2002) was described by Duffy et al. (1993) and O'Brien et al. (1995). They developed a cement mortar with an aggregate to binder ratio (9:1) which is high in comparison with mortars typically used on granite buildings. This mix has low free calcium content and was considered to have mechanical properties suitable for repointing granite buildings. It has been used on some buildings in Dublin.

Calcium sulphate has been shown to play a significant role in the decay of granite (O'Brien et al. 1995), and this calcium can be derived from pointing mortars, especially from those rich in lime, with a high free calcium content. This could make the use of low free lime mortars desirable if they are suitable with respect to other important characteristics.

Table 5.5 Mortar compositions tested by Mosquera et al. (2002).

Mix	**Materials**	**Ratio (by weight)**
1	Sand/cement	3:1
2	Sand/cement/admixture[a]	6:1
3	Sand/cement/admixture[a]	9:1
4	Sand/lime/cement	6:1:1
5	Sand/pozzolan/cement	6:1:1
6	Euromix® (sand/cement/admixtures)	6:1[b]

[a] WRDA1 27 (Grace Canada) was included. Dosage was 240 ml/100 kg of cement.
[b] According to manufacturer's specifications.

Table 5.6 Mortars' properties. Mosquera et al. (2002).

Mix	Porosity (%)	Strength (N/mm^2)	Modulus 10^{-3} (N/mm^2)	Diffusivity 10^{-6} (m^2/s)	Ca^{2+} (mg/l)/g sample[a]
Sand/cement 3:1	16.68	37.0	20.0	0.85	55.5
Sand/cement 6:1	18.34	9.5	8.1	1.58	41.5
Sand/cement 9:1	24.60	5.2	2.4	2.53	26.0
Sand/lime/cement	24.21	6.2	1.6	7.54	77.0
Sand/pozzolan/cement	22.70	6.5	4816.0	1.89	50.5
Euromix®	32.84	23.0	12.0	3.27	98.0

[a] This means milligram of soluble calcium extracted from 1 l of deionised water per gram of sample.

5.2 Comparison of lime to "lime replacement" products in cement-lime mortar

Table 5.5 Results of "lime replacement" mortar study.
(Adapted from: National Lime Association Building Lime Group, October 2000. www.lime.org/)

Series	Lime or lime replacement type	Total water collected at flashing (28 days) (litres)
A	Type S hydrated lime	23.9
B	Type S hydrated lime	11.0
C	Type S hydrated lime	16.0
D	Type S hydrated lime	11.3
E	Pozzolanic lime replacement	43.3
F	Proprietary mixture lime replacement	34.0
G	Proprietary resin lime replacement	64.8

The results shown in Table 5.5 indicate that mixes containing lime replacement materials have, on average, three times more wall leakage than assemblages made with the same mortar type containing Type S hydrated lime.

Figure 5.1 Data from Table 5.4. Time to first dampness (hours), comparing masonry cement (shown in red) and cement-lime (in blue) mortar mixes. Study numbers are abbreviated as shown in Table 5.4.

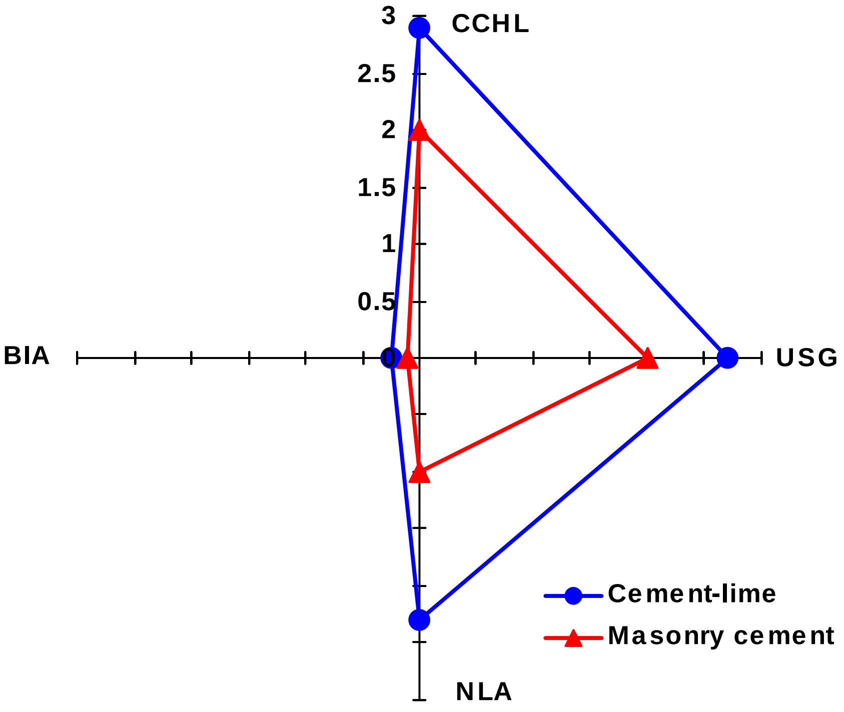


Figure 5.2 Data from Table 5.4. Time to first visible water, comparing masonry cement (shown in red) and cement-lime (in blue) mortar mixes. Study numbers are abbreviated as shown in Table 5.4.

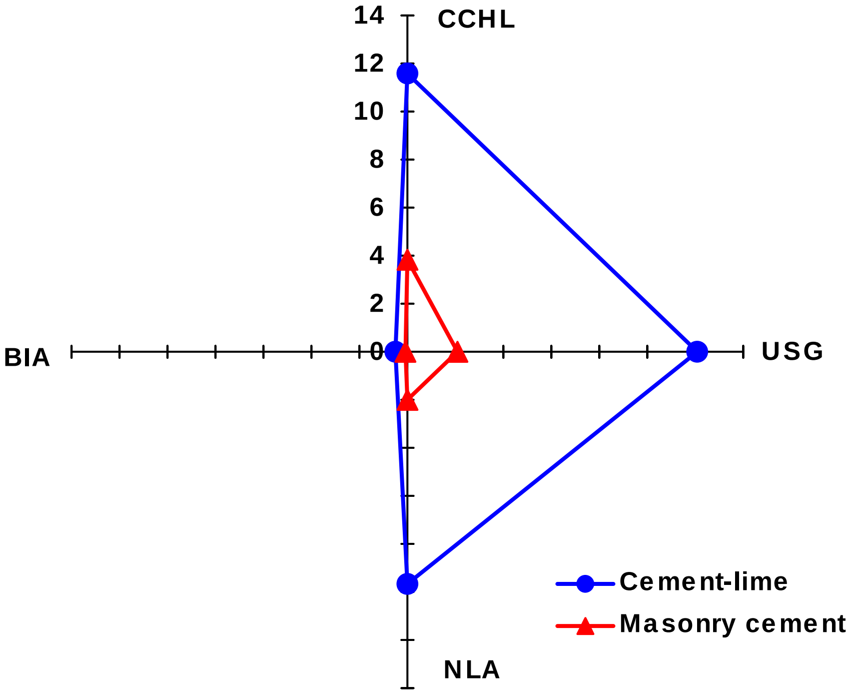


Figure 5.3 Data from Table 5.4 Percentage dampness (%) through masonry walls after 4 hours exposure to driving rain. Comparing masonry cement (shown in red) and cement-lime (in blue) mortar mixes. Study numbers are abbreviated as shown in Table 5.4.

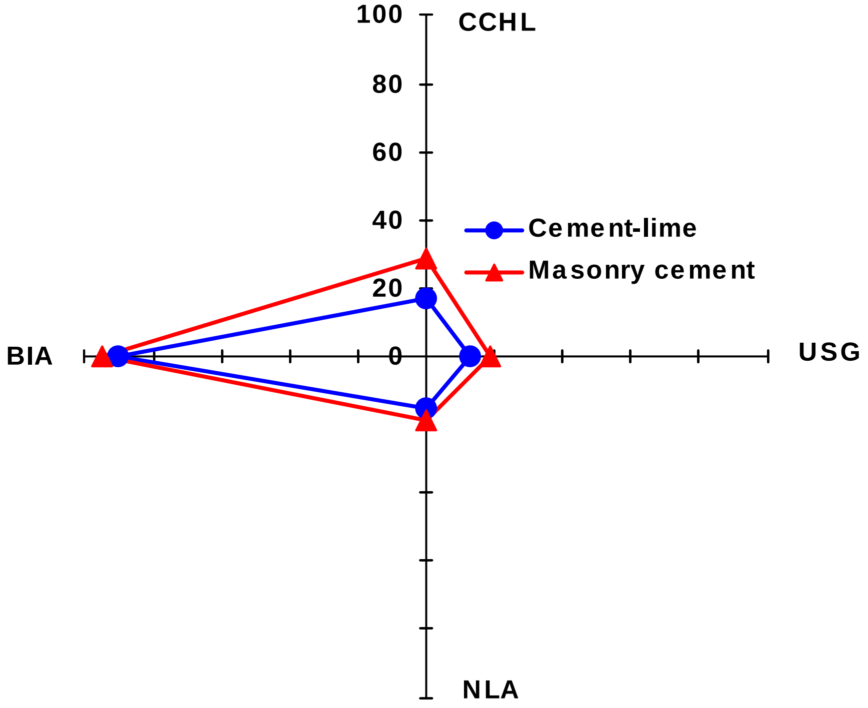
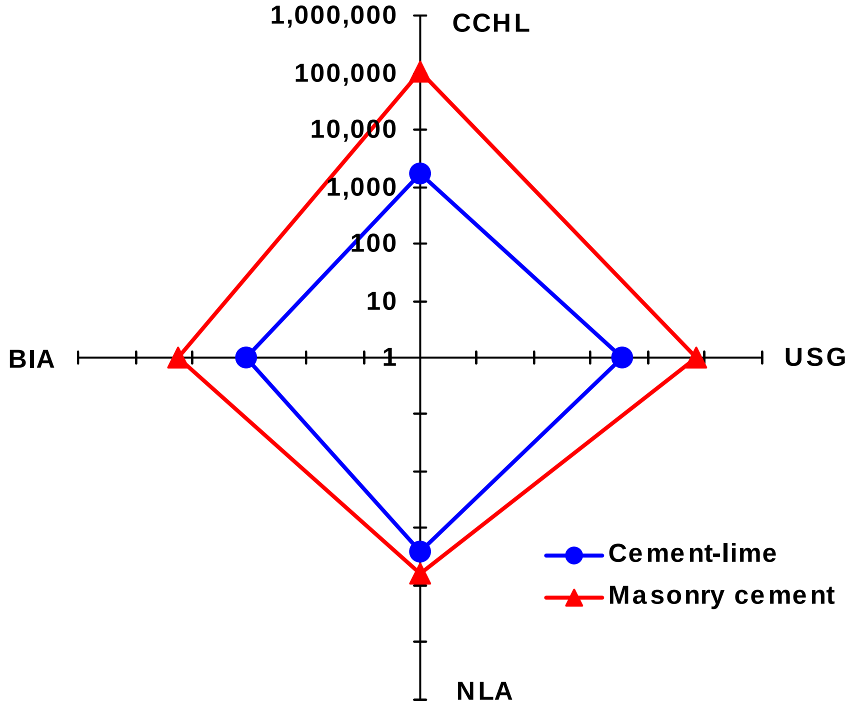


Figure 5.4 Data from Table 5.4. Total water leakage through panels in 72 hours. Comparing masonry cement (shown in red) and cement-lime (in blue) mortar mixes. NB Scale is logarithmic. Study numbers are abbreviated as shown in Table 5.4.



References for section 5

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Parts of this section were adapted from a study ("Lime-based mortars create water tight walls") published by the National Lime Association, Arlington, VA