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STRENGTH CONSIDERATIONS IN MORTAR AND MASONRY

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Preface

Over the years considerable research has been conducted on masonry mortar, some of which has been obscure or forgotten . . . and much of it contradictory in its conclusions and/or interpretation of the findings . . . and there is often disagreement among the researchers on the significance of tests, etc. Yet, preponderant or majority opinions on this collective research is often possible to glean. To this end the National Lime Association's staff has made a study of what appears to be the most significant research in the mortar field.

The results of this study are being summarized in a series of articles categorized into the principal properties and considerations of mortar, such as durability, efflorescence, bond, volume change, strength, and workability, along with selected bibliographies. The first of this series of consolidated research digests is Mortar Durability and the second (this issue) is Strength Considerations in Mortar and Masonry.

One inescapable general conclusion from this study is that an overwhelming majority opinion among the independent authorities consistently substantiated the need for *both* lime and portland cement in a well balanced, all-purpose mortar. The lime referred to is either hydrated lime or lime putty made from quicklime and may be either dolomitic or high calcium types. This should never be confused with pulverized limestone (calcium carbonate) that is sometimes erroneously called "lime", and which is inert in mortar and has none of the properties inherent with burned lime products. So, whether a conventional lime-cement mortar or a prepared one-bag mortar is used, be sure the mortar contains a bonafide lime that meets ASTM Specification C 207—or C 5 and enough of it.

Strength Considerations in Mortar and Masonry

Obviously a material, like mortar, that is used to bind masonry units together into a monolithic-like mass and which must often support heavy loads, must possess an *adequate* strength with a generous safety factor. Mortar strength, however, is often greatly over-emphasized to the detriment of other essential mortar properties, such as workability, water retentivity, and bond strength . . . and those builders who strive for high or maximum mortar strengths usually obtain inferior mortar for normal, above-grade masonry construction.

History—Before the advent of portland cement in the United States in the latter part of the 19th century (1886 on), all of the masonry mortar was a straight lime-sand mix that inherently possessed very low compressive strength. True, some of the lime* produced was derived from impure limestone that had varying (but usually faint to moderate) hydraulic qualities; other pure limes were mixed with crude, unwashed sand containing clay that acted like a mild pozzolan with the lime. While both of the latter types of mortars possessed slightly more strength than the pure ("fat") lime—clean sand mixes, all would be regarded today as extremely weak in compressive strength (ranging between 50 to 300 p.s.i. in 28 days). Yet these mortars as a whole were still able to support satisfactorily and safely some large masonry structures (for that time); and they endured, in some cases for centuries, without tuckpointing. (See NLA Masonry Mortar Technical Notes #1 on Durability of Mortar and Masonry).

These early lime mortars were never actually deficient in *ultimate* strength—only in *high early* strength since they gained strength largely by recarbonation, a very slow process. This meant that construction had to progress from floor to floor very slowly (long "green" strength periods). As the tempo of construction accelerated, the advantage of adding portland cement to mortar was a logical consequence because of its rapid setting qualities. Thus entered a new era of high speed modern construction early in the 20th century.

Soon, portland cement became recognized as a desirable or essential ingredient in mortars, and it was mixed with lime and sand in many varying proportions. 28-day and ultimate mortar strengths were, of course, markedly increased. Gradually, a "high strength complex" developed among many builders, so that the cement increment was steadily increased until some builders in the 1915-1930 period were using straight cement mortars—without lime—espousing the erroneous theory that "the stronger the mortar, the better." Memories are short. The long history and proven durability of the old straight lime mortars were largely forgotten.

Straight cement and high cement mortars, however, soon exhibited serious shortcomings that dwarfed their questionable advantage of high ultimate strength. Without lime (or enough of it) these mortars proved to be stiff and unworkable so that the joints were incompletely filled; they possessed low water retentivity so that absorptive masonry units sucked the water from the mortar before it set, causing the mortar to "pancake", and preventing it from adhering to the mortar-unit interface. This coupled with an inadequate extent of bond, characterized by frequent voids and holes, caused by poor mortar workability, led to an epidemic of leaky masonry. Even in cases where initial bond between mortar and unit was established due to use of denser units and better workmanship, often eventually widespread separation cracking occurred at the mortar-unit interface (broken bond), an easy prey for driving rains to penetrate. This was caused by the inherent tendency of a rich cement mortar to shrink. Although this type of mortar was extremely hard, and high in compressive strength, it was rigid and very brittle. The problem of leaky masonry became sufficiently serious to warrant an investigation by such research organizations as the National Bureau of Standards and M.I.T. in the late 1920's and early 1930's.

The conclusions from these studies influenced a change in mortar proportions and a modification of "the high strength complex", with the re-introduction of lower strength mortars that contained much higher proportions of lime (1:1:6 and 1:2:9 mortar mixes, cement, lime and sand, respectively).

Strength Tests—Before 1920 mortars were tested for both tensile and compressive strengths about equally, and to a much lesser extent, in transverse strength. But in the past forty years, most strength tests have been in compression, involving 2" x 2" mortar cubes or larger bars, molded in non-absorptive metal units. Other more elaborate tests have involved 2-bat brick assemblages and brick wall panels or piers in which the compressive strength of the harder brick is the dominating factor in determining wall or assemblage strength. Tensile strengths can usually be estimated from known

* Refer to Appendix for definition of lime.

compressive strengths. On an average, the former would be about 12% of the latter value (a range in values of 7-20% is found in the literature).

Emley[1] was the first to recognize how even slight modifications in mortar test procedures could greatly affect strength values. In effect he said, "Unless the test procedure and material used are *minutely* described, mortar values reported are meaningless." While most investigators used standard ASTM test procedures, frequent modifications were made in them, particularly in *curing conditions,* either because of curiosity, convenience, or inadvertence. Variables, noted by Emley, that could singly alter strength values as much as 25-200% were:

1. Type of lime, whether high calcium or dolomitic; hydrate or putty from quicklime.
2. Slight changes in atmospheric humidity and temperature in curing.
3. Size and shape of specimen.
4. Skill and experience of laboratory technician.
5. Slight changes in sand gradation.
6. Consistency of mix—percent of initial flow.
7. Slight variation in proportions.
8. Modifications in curing conditions.

Some curing conditions of mortar specimens are definitely unfair to lime-based mortars[2,3]—particularly the underwater cure. Curing in a damp closet for 28 days is reasonable for 1:1:6 and 1:2:9 mortars. For very high lime mortars, the damp closet cure is rather harsh, and laboratory air is recommended.

There is considerable disagreement, however, among masonry researchers on the significance of these strength tests. Authorities, like Voss,[4] Staley,[5] Emley,[1] and MacGregor,[6] regard the assemblage and wall panel type of strength tests as the only ones of any value. They claim that the mortar cubes and bars do not remotely emulate bricklaying (wall) conditions, such as effect of absorption by masonry units, consolidated weight of wall, and particularly the profound influence of the strength of the units. As a result, they conclude that these latter tests are meaningless, except as a system of mortar classification by compressive strength categories. Others, like Palmer,[7] Anderegg,[8] and Connor,[9] tended to this same view, but also felt that strength data on cubes or bars was of minor, secondary value since mortar becomes an integral part of the wall, even though it occupies less than 5% of the wall area.

Most of these investigators did not worship high

TABLE I. *Factors of safety as related to masonry materials and assemblage compressive strengths.* (Staley, ref. #5)

Mortar				Brick					Mortar Strength (p.s.i.)		Pier Strength (p.s.i.)		Factor of Safety*		Ratio of Pier Strength to Mortar Strength		Ratio of Pier Strength to Brick Strength	
Proportions by Volume			Lime Used	Type	Absorption		Strength (p.s.i.)		Age		Age		Age of Piers		Age		Age	
C	L	S			Initial Rate	Total %	Comp.	Modulus of Rupture	28 Da.	6 Mos.	28 Da.	6 Mos.	28 Da.	6 Mos.	28 Da.	6 Mos.	28 Da.	6 Mos.
1	0	2.5	None	Sand Struck Common	High	16.7	4840	709	4385	4860	1997	2555	9.9	12.7	.46	.53	.41	.53
1	1	5	Norm. Dol.						1525	2380	1640	2375	9.2	11.8	1.20	1.00	.38	.49
1	2	7.5	" "						511	1525	1498	1998	7.4	10.0	2.94	1.30	.31	.42
1	1	5	H.C.						1015	1840	1607	2178	8.0	10.3	1.58	1.19	.33	.45
1	2	7.5	"						334	900	1324	1748	6.5	8.7	3.97	1.94	.28	.36
1	0	2.5	None	Water Struck Common	Low	1.8	10400	1585	3007	4890	4406	5080	22.0	25.4	1.46	1.04	.42	.49
1	1	5	Norm. Dol.						1181	2640	2530	3640	12.6	18.2	2.15	1.38	.24	.35
1	2	7.5	" "						667	1700	2160	2770	10.8	13.8	3.25	1.64	.21	.27
1	1	5	H.C.						911	1765	2380	3175	11.9	15.8	2.60	1.80	.23	.30
1	2	7.5	"						370	860	2195	2598	11.0	13.0	5.94	3.02	.21	.25
1	0	2.5	None	Wire Cut Clay	High	1.5	9530	1758	3953	5720	6260	6455	31.0	32.2	1.58	1.12	.66	.67
1	1	5	Norm. Dol.						2184	2730	4155	4800	20.7	24.0	1.90	1.76	.44	.50
1	2	7.5	" "						1124	1830	3040	3625	15.2	18.1	2.70	1.98	.32	.38
1	1	5	H.C.						1165	2440	3670	3725	18.3	18.6	3.16	1.53	.39	.39
1	2	7.5	"						437	813	2770	3015	13.8	15.0	6.35	3.70	.29	.32

* Based on 0.75 × Pier Strength and Design Load of 150 p.s.i.

NOTE: Under mortar proportions above, C = cement, L = lime, and S = sand.

mortar strength. They were responsible, however, (probably unwittingly), in influencing the classification of mortar standards and specifications (ASA A.41 and ASTM C-270) that are based on compressive cube strength. This system of mortar classification is misleading to builders and engineers, because of the possible inferred connotation that the highest strength mortar types and proportions are the best; the lowest strengths are the poorest, etc. This was *not* the intention to convey such an impression. A straight cement mortar may contribute to a strength factor of safety of 40 to 60+, an amount far in excess of what is needed. Safety factors of 5-10 are completely adequate; no additional value can be attached to masonry that possesses higher safety factors. Possibly at one time, strength was a more valid consideration than it is today, since a modern 1:1:6 mortar, containing Type S hydrated lime, is stronger in compression than a straight (1:3) cement mortar was in 1915. This is due to the fact that modern portland cements are now several times stronger in compression than formerly, and the modern Type S lime hydrates develop greater strength than other types of lime.

Results of Research on Masonry Strength—Staley's[5] research on the influence of various types of clay brick, and widely varying mortar proportions on the 28-day and 6-month compressive strength of 8" x 8" brick piers and the factors of safety based on a hypothetical design load of 150 p.s.i. is summarized in Table I. Note that the lowest factors of safety at 28 days and 6 months were 6.5 and 8.7, respectively. Comparing the two extremes in mortar compositions, it is found that strengths of straight cement mortar average 10 times (1000%) more than the highest lime content mortar, yet the pier strengths with the weakest mortar (highest lime content) are only 30-55% less than with the strongest mortar . . . and still possess very ample factors of safety.

Similar research by Davey[10] of the British Building Research Station parallelled Staley's findings. In fact, he reports that there is practically no change in strength of brick piers with a substitution of up to 50% lime by volume for cement, in spite of the fact that the mortar strength drops sharply as revealed in Figure 1. Stang, Parsons, and McBurney,[11] of the National Bureau of Standards, and Palmer[7] independently, also concluded that lime up to 50-60% of the volume of the total cementitious material (i.e., lime plus cement) can be used in a 1:3 mix without any reduction in pier strength of consequence.

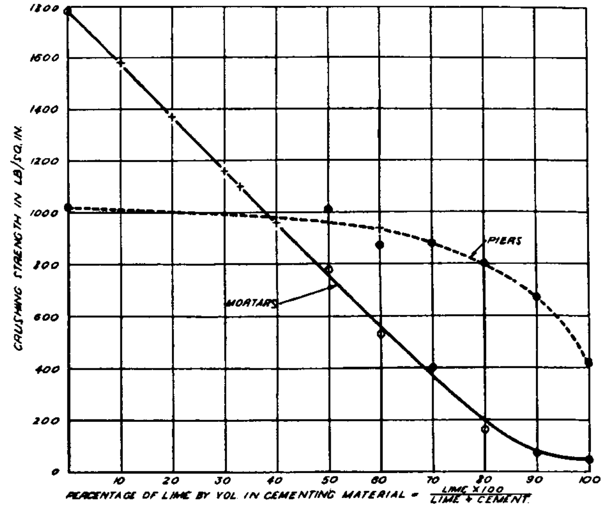


FIG. 1. Relationship of compressive strength of mortar and pier (wall assemblage) strength. Strength of brick was 2700 p.s.i. (Davey, ref. #10).

With respect to brick pier strength tests, Voss[4] contended that 6-month strength tests were far more meaningful than 28-day strengths since rarely is a building occupied before a 6-month construction period, small private homes excepted. He calculated the load imposed on a typical 4-story school building with 26' classroom spans of 16" thick, solid, brick walls at grade at only 80 p.s.i. Comparing such loads with the substantial pier strengths and factors of safety for all mortar and brick combinations developed by Staley (Table I), he expresses amazement that so many architects and engineers are striving for high or maximum strengths . . . and likens factors of safety to "factors of ignorance" since high mortar and masonry assemblage strengths sacrifice most of the other essential or desirable qualities in mortar. Masonry units of 10,000 p.s.i. and mortar of 3000 p.s.i. will develop approximate safety factors of 50; factors of 5-15 are completely adequate, he maintains, and far more desirable. As evidence, he reminds the reader of the hundreds of schools, factories, warehouses, and apartment buildings erected before 1900 in which straight lime mortars (1:3) were employed. These endured even though many of these old mortars tested as low as 50 p.s.i. in compression.

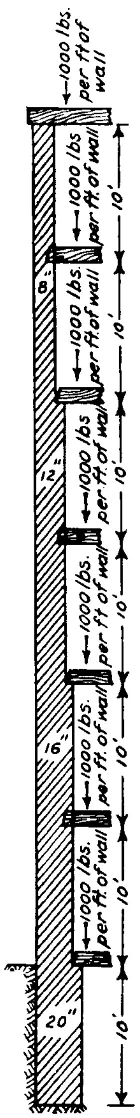
Authors[12] of the National Bureau of Standards Circular No. 30 generally concurred with Voss' opinion. Quoting from this circular, they report as follows:

> This question of the strength of a mortar is apt to be given undue weight. Since masonry is assumed to

weigh 150 lbs./cu. ft., then, the compression load (in lbs./sq. in.) at the bottom of a wall will be $\frac{150}{144}$ times its height in feet. A mortar with a compressive strength of 100 p.s.i., should, according to this reasoning, be able to carry a wall $100 \times \frac{144}{150} = 96$ ft. high, or about 9 stories. The compressive strength of the mortar is usually measured by crushing 2" cubes. For a homogenous material, the unit compressive strength varies with the shape of the specimen, being dependent upon the ratio between the least horizontal dimension and height. In a cube this ratio is one. A mortar joint in a wall may possibly be 9" wide by 30' long by ½" thick. In the joint the ratio is $9 \div \frac{1}{2} = 18$. If a mortar has a strength of 100 p.s.i. when tested in the form of a cube, it should theoretically have a strength of 1800 p.s.i. when laid up in the wall.

Many years ago (World War I era), a renowned Swedish building technologist—Krueger[13]—studied the loads imposed on mortar beds. The results of his research are consolidated in Table II showing the tapering thickness of a load-bearing brick wall of 6 stories (on the left), individual wall and floor loads, cumulative loads, and the loads in p.s.i. for each floor. A low strength brick was used with a weak 1:3 straight lime-sand mortar that developed a masonry assemblage strength of only 410 p.s.i. Yet this low strength assemblage had a safety factor of about 8 or higher for the exemplified building in Table II.

TABLE II. *Loads imposed on mortar beds at various floor levels* (Krueger, ref. #13).



Story	Load Increments - lbs.		Accumulated Loads - lbs			Area of Mortarbed sq. in. per ft of wall	Load per sq. in. on Mortarbed
	Wall	Floors	Wall	Floors	Total		
Roof	0	1000	—	1000	1000	96	10
6	600	0	600	0	1600	96	17
5	600	1000	1200	2000	3200	96	33
4	900	1000	2100	3000	5100	144	35
3	900	1000	3000	4000	7000	144	49
2	1200	1000	4200	5000	9200	192	48
	1200	1000	5400	6000	11400	192	60
Found.	1500	1000	6900	7000	13900	240	58

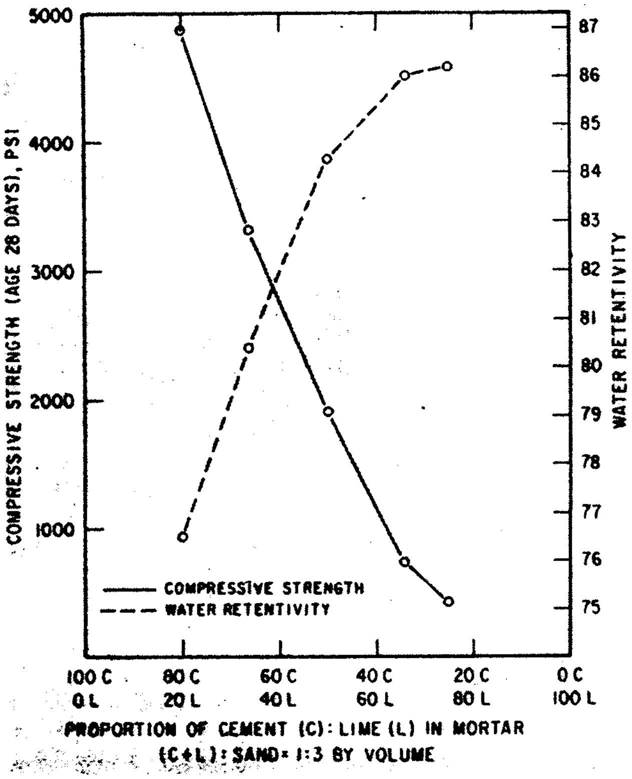


FIG. 2. Relation between mortar composition, compressive strength and water retentivity. (Ritchie, ref. #14)

Compromise Necessary for Balance—Ritchie[14] postulates that the mortar proportion of optimum efficacy is usually necessarily a compromise between two extremes of high cement or high lime content. If a high strength mortar is desired, the increased increment of cement contributes toward poorer workability, lower water retentivity, and rapid stiffening, all of which are undesirable in a well-balanced mortar. Conversely, lime contributes little to strength, but it does provide the desirable characteristics of workability, high water retentivity, and maximum extent of bond. This is born out in Figure 2. Therefore, he concludes that a compromise proportion of 1:1:6 and 1:2:9 (cement, lime and sand, respectively) is the logical solution to mortar proportioning.

Concrete Block—Clay brick, of course, is much stronger in compression on an average than concrete products, particularly the lightweight, cavity-type block; also 8″ load-bearing walls, which are more widely used today, develop greater loads than 12″ or 16″ walls, since the load and stresses are distributed over a more restricted area. The resulting loss in assemblage strength coupled with the greater imposed loads have influenced some engineers into striving for maximum or very high mortar strength to "beef up" the assemblage strength. But again, consider the safety factors involved; the fact that the mortar joint only occupies 5% or less of the area of a wall (less space than with clay brick); that high cement mortars and even 1:1:6 mortars are usually higher in compression than the units themselves. There is considerable support to the theory that mortar should never be stronger than the masonry unit since under settlement or deflective stresses the unit, rather than the mortar, is more likely to crack.

Mortar was originally conceived as a means of bedding masonry units and bonding them together. In this vein, mortar serves masonry in the comparable capacity of a gasket or washer so that ideally some resilience is necessary to "cushion" deflection. Rigidity in mortar is incompatible with this concept.

Curtain Walls—In non-load-bearing walls, like curtain walls, strength is of even less importance. The only strength requisite is for resistance to the force of lateral pressure, caused by strong winds and gales. In hurricane areas greater strength is necessary—but not compressive strength. High bond strength, developed by an adhesive, plastic mortar that provides maximum extent of bond, should be the prime objective. (For information on bond strength, refer to NLA Masonry Mortar Technical Notes #3).

High Early Strength—The essential mortar property of high early strength is provided most efficiently by portland cement. Contrary to the opinion of some engineers, not much cement is necessary to accelerate the set of mortars markedly in warm weather.[15] One part of portland cement to 2-3 parts of lime by volume will easily suffice, with the cement in effect being used to gauge the lime mortar. In cold weather construction, however, the setting time may be too slow, so that equal parts of portland cement and lime by volume may be desirable. Thus, cement is primarily needed for mortar to provide fast setting and high early strength—not for ultimate high mortar or masonry assemblage strength—in conventional masonry construction.

Compressive Strength Values—Mortar strength data published in the literature varies tremendously, depending upon strength test details, particularly curing conditions and types of mortar materials used—lime, cement and sand. Air entrainment[16,17] invariably lowers the strength of all mortar types; with modest amounts of air, strength losses are slight, but with percentages of entrained air over 15%, losses in strength become appreciable

TABLE III. *Approximate ranges in compressive strength for various mortar proportions and types.*

Mortar Proportion [1]			ASTM Mortar Designation	Type of Lime or Cement	Approximate Compressive Strengths		
C	L	S [2]			*Min.*	*Max.*	*Average*
1	0	2-3	—	—	3800	4600	4200
1	¼	3	M	—	3000	3800	3400
1	½	4½	S	—	2300	3000	2600
1	1	6	N	Type S	1500	2400	1800
				Putty or Type N	800	1800	1200
1	2	9	O	Type S	750	1200	900
				Putty or Type N	350	750	500
0	1	3	—	Type S	125	400	200
				Putty or Type N	50	300	125
1MC	—	3	O	M.C., Type I	500	800	750
1MC	—	3	N	M.C., Type II	800	3000	1500
1	3	12	K	Type S	300	600	450

[1] C = Portland Cement; L = Lime; S = Sand; M.C. = Masonry Cement.

[2] Strength values include possible adjustment of 1:3 total cementitious-sand ratio by up to ±25%.

as the air content rises. Table III provides a range and approximate average of mortar strength values for all of the major mortar types and proportions, many of which are recognized by ASTM.[18] (Generally, field strengths are lower than the lab values shown in Table III, primarily because mortars are mixed at wetter consistencies in the field).

Miscellaneous Factors Affecting Mortar Strength

The concensus of the data from mortar researchers on mortar strength indicates the following: 19,20,21 and others cited

1. Effect of limes (strength comparisons at 28 days)
   - a. Dolomitic hydrates *per se* in 1:3 (straight lime) mortar appear to develop nearly twice as much compressive strength as high calcium hydrates and putties from high calcium quicklime on an average.
   - b. Type S hydrated limes *per se* appear to develop in lime-cement mortars two-thirds greater strength than Type N hydrated limes on an average; however, the Type S develop only about 25% more strength than dolomitic Type N hydrates.
   - c. A 1:2:9 mortar with Type S lime develops greater strength than most hydraulic limes.
   - d. A 1:1:6 mortar with Type S lime develops greater strength than the majority of masonry cements.
   - e. Type N hydrates develop 25% more strength on an average than putty from high calcium quicklime.
2. The tensile strength of all proportions of lime-cement mortars, as well as straight cement and lime mortars, average about 12% of the compressive strength values at 28 days. (Range is from 7 to 20%).
3. Regardless of mortar composition, both tensile and compressive strength values increase as the water-cement ratios are decreased.
4. Measured at standard consistencies or flows, the water-cement ratios steadily increase with increasing increments (proportions) of lime. (Ranges between a ratio of 1.0 for a 1:0:3 (straight cement) mortar to about 3.5 for a 1:3:12 mortar). This helps to explain #3 above and the fact that strength decreases as lime proportion increases.
5. Strength of mortars decreases steadily with increasing increments of entrained air. The magnitude of loss is about 20% between 0% and 15% air; much higher losses over 15% air.
6. A small amount of cement (25% by volume) greatly accelerates (several hundred percent) the set of high lime mortars. Further increments of cement will increase setting rate time steadily but at a slower rate as measured by penetrometer test. (E.g., in one hour the Vicat needle only penetrates a 1:2:9 mortar about 25% further than a 1:¼:3 mortar; at 2 hours, however, penetration is much greater.)
7. In comparing all proportions of mortars at 75% and 110% initial flow, greater 28-day

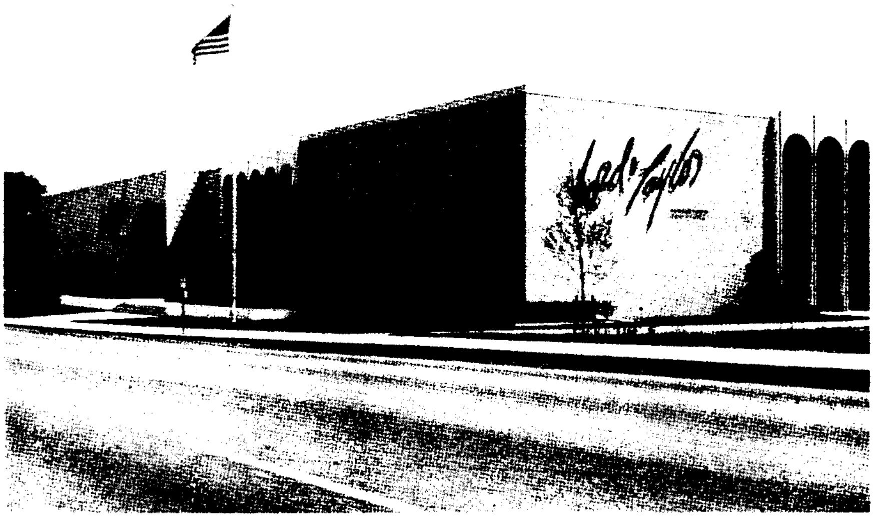


FIG. 3. Attractive masonry construction of Lord & Taylor Department Store, Jenkintown, Pa. A 1:2:9 mortar was used.
General Contractor: Hughes-Foulkrod Construction Company, Philadelphia, Pa.
Masonry Contractor: John B. Kelly Company, Philadelphia, Pa.
Architect: Everett & Gilboy, Allentown, Pa.

strengths are obtained for 0:1:3 and 1:3:12 (very high lime) mortars at 110% initial flow; with all other lower lime content mortars the reverse is true, with drier mortars developing greater strength. In the latter, gain in strength at 75% flow increased as cement proportion increased.[3]

8. Percentage strength gains between 28 days, 6 months or 1 year are much greater with lime-cement (1:1:6 and 1:2:9) mortars than with straight cement mortars by about 40% on the average.[3,4] This indicates that lime mortars gain strength much more slowly, but over a longer period of time.
9. No unanimity is apparent on effect of consolidation on wall or mortar strengths. Staley[5] feels that there is a gain in strength, and it is proportionately greater with high lime mortars because it beds more easily due to greater workability.
10. Generally, workability in mortar decreases as strength increases, in absence of entrained air, and vice versa.
11. Tensile bond strength, as measured with the ASTM brick couplet test, generally increases as compressive strength increases, in absence of entrained air. Extent of bond, however, which is more significant than bond strength, generally decreases with increased compressive strength.
12. In general, decreases in either water retentivity or sand-carrying capacity parallel increases in strength for all mortars.
13. 28-day strengths of mortars, regardless of lime content, average about 60% higher than 7-day strengths.
14. Curing methods (of cubes):
    a. High cement mortars of 1:¼:3 develop equal strengths whether they are cured in seven days in damp closet and 21 days under water (standard ASTM test) or 28 days in damp closet.
    b. Strengths of 1:1:6 and 1:2:9 mortars are much higher when cured 28 days in damp closet than with ASTM test.
    c. Curing 7 days in damp closet, 18 days in water, and 3 days in laboratory air produce greater strength than in 14-b above, for 1:1:6 and 1:2:9 mortars, showing beneficial effect of wetting and drying on strength.
    d. Curing in air for 28 days develops higher strengths than 28 days in damp closet for 1:4:15 mortars or straight lime mortars.
15. With most masonry sands, an increase in the proportion of total cementitious material (C + L) up to about 25% richer than the conventional 1 to 3 ratio increases mortar strengths by 10-25%.

***Conclusion**—Thus, lime-cement mortars, notably the 1:2:9 proportion (cement, lime and sand, respectively), provide completely adequate wall strength with an ample safety factor for all standard masonry construction.* But *most* important, the high lime content contributes other essential characteristics to a well-balanced mortar—improved workability and water retentivity that provides maximum adhesion and a high extent of bond between the unit and the mortar; a safeguard against separation cracking at the mortar—unit interface, caused by shrinkage or deflection that commonly occurs with hard, rigid, brittle mortars; and as a consequence, watertight joints. Actually cement is mainly a necessary mortar ingredient for only one reason: to provide quick setting or *high early strength* so that construction can proceed at a rapid pace.

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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 or oyster shells by calcination at high temperature (2000° 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—Types N and NA and Types S and SA hydrated limes, applicable to both high calcium and dolomitic (high magnesium) hydrates. The Types S and SA (special and special air-entraining hydrated lime) are differentiated from Types N and NA (normal and normal air-entraining hydrated lime) principally by their ability to develop high early plasticity, higher water retentivity, and by their limitation on unhydrated oxide content. The air content of cement-lime mortars made with Types N or S hydrated lime shall not exceed 7%, and those made with Types NA or SA hydrated lime shall be between 7 and 14%.

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

In this series of NLA Technical Notes, a "high lime mortar" is generally considered as comprising one part cement, two parts lime and approximately nine parts sand. The National Lime Association recommends this 1:2:9 proportion as an excellent mortar for general use.