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Influence of Lime in Mortar on the Expansion of Brick Masonry

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by
T. Ritchie

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L'INFLUENCE DE LA CHAUX DANS LE MORTIER SUR LA DILATATION DE LA MACONNERIE DE BRIQUE

SOMMAIRE

Les mortiers contenant de la chaux dolomitique normalement hydratée causent une plus grande dilatation du briquetage des piliers que les autres mortiers. Parce que la dilatation du briquetage est plus considérable verticalement que horizontalement et parce que la dilatation est grandement empêchée par une charge relativement légère, les mortiers contenant de la chaux dolomitique normalement hydratée n'ont pas endommagé le briquetage par leur dilatation. Les résultats de cette étude offrent une explication au comportement des bâtiments de briques dont le mortier contient de la chaux dolomitique normalement hydratée, même sidetels mortiers ont une grande capacité de dilatation.

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T. Ritchie¹

Influence of Lime in Mortar on the Expansion of Brick Masonry^{*}

REFERENCE. Ritchie, T., "Influence of Lime in Mortar on the Expansion of Brick Masonry," *The Reaction Parameters of Lime, ASTM STP 472*, American Society for Testing and Materials, 1970, pp. 67-81.

ABSTRACT: Mortars containing normally hydrated dolomitic lime caused greater expansion of brickwork piers than other mortars. Because the expansion of brickwork was much greater in the vertical direction than horizontally, however, and because the expansion was inhibited greatly by a relatively slight load, mortars containing normally hydrated dolomitic lime did not damage the brickwork from their expansion. The results of this study offer an explanation for the satisfactory performance of brick buildings with mortars containing normally hydrated dolomitic lime even though such mortars have great capacity for expansion.

KEY WORDS: mortars (materials), masonry, expansion, evaluation, tests, calcium oxides, brick structures, cements, mechanical properties

Normally hydrated dolomitic lime, produced in the Toronto, Ontario, area since before 1920² and extensively used as an ingredient of cement:lime:sand mortars for masonry, has the effect of rendering such mortars grossly expansive on autoclaving, undoubtedly because in the process of preparing the lime some of its magnesium oxide remains unhydrated, later to hydrate, accompanied by great expansion, in the autoclave. As the excessive expansion of cements and mortars on exposure to steam at high pressure and temperature in the autoclave generally is considered to indicate their excessive expansion in service, this study was undertaken to determine if mortars containing normally hydrated dolomitic lime cause

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² Ontario Department of Mines, Annual Report, Vol. 34, Part 1, 1925. (This report gives production figures for hydrated lime in 1920 and states that four lime plants in Ontario, three in the Toronto area, were equipped to produce hydrated lime, the major portion of the production being consumed by the building trades.)

mortar and brickwork to expand, and, if so, to what extent such expansion damages the brickwork and hence the building it forms.

Brick Piers

The dimensional changes of brickwork were studied by using 26 brick piers constructed with nine masonry mortars of various compositions and amounts of autoclave expansion and three types of bricks. Each pier was about 3 ft wide, 1 ft thick, and 3 ft high, and was designed as a hollow structure of walls one brick (approximately 4 in.) thick. The pier was constructed on a brick foundation almost 1 ft high and was separated from it by a flashing material. The top of the pier was covered by a roof with a slight overhang.

On both the east- and west-facing walls of the piers metal pins were used to measure vertical and horizontal dimensional changes. These pins, spherically ended and projecting about 1 in. from the brick surface, were fastened in the bricks before the walls were laid; they were approximately 16 in. apart horizontally and 17 in. apart vertically. To measure the distance between the pairs of pins a gage was used that consisted of a micrometer head, reading to one ten-thousandth part of an inch, mounted in a frame of Invar metal. The measurements of the piers were compared with those of an Invar standard to determine pier dimensional changes. Initial readings for each pier were taken as soon as possible after construction was completed; frequent readings were taken in the first few weeks following construction, but then were taken only twice each year, in the summer months.

Bricks

Of the three types of bricks used to construct the piers two were clay (A and B) and one was concrete (C). Their absorption, strength, and durability properties are listed in Table 1. Measurements also were made of the length changes of the bricks using a Whittemore gage and metal reference pins attached to both faces of the brick. Two samples of each brick were stored under three different conditions: indoors at 50 percent relative humidity and 73 F; indoors at 100 percent relative humidity and 73 F; and outdoors exposed to rain and snow.

The length changes of the bricks in six years are shown in Fig. 1. The two clay bricks stored at 50 percent relative humidity gradually expanded while the concrete brick shrank. Storage at 100 percent relative humidity caused slightly greater expansion of the clay bricks, but the concrete brick reversed its previous behavior and expanded. In six years the clay bricks stored in high humidity expanded about 0.03 percent, while

TABLE 1—Range of values of properties of the bricks (20 samples tested for water absorption and 5 samples tested for strength and durability).

Property	Brick A (Clay)	Brick B (Clay)	Brick C (Concrete)
Initial rate of absorption, g/min/30 in ²	14.9 to 32.4	50.0 to 77.4	53.8 to 166.7
Absorption, %, 24 h.....	5.7 to 8.5	9.8 to 13.1	6.7 to 10.2
Absorption, %, boil.....	7.9 to 10.1	13.0 to 16.0	10.2 to 12.6
Saturation coefficient.....	0.73 to 0.84	0.74 to 0.82	0.64 to 0.81
Compressive strength, psi..	11,600 to 18,100	7,000 to 11,700	2,600 to 2,900
Weight loss after 50 freeze- thaw cycles, %.....	0.01 to 0.08	0.14 to 0.25	broke between 35 and 50 cycles

the expansion of the concrete brick was approximately 0.1 percent. All the samples stored outdoors expanded, the concrete brick even more than it had in storage at 100 percent relative humidity. After three years' outdoor exposure both clay bricks showed considerable cracking indicating the effects of frost action.

Mortars

The compositions of the nine mortars used to construct the piers are given in Table 2. Four of the mortars were prepared from masonry

FIG. 1—Length changes of bricks under various storage conditions.

TABLE 2—*Mortars used in the piers.*

Mortar No.	Constituents	Proportions, by volume	Autoclave Expansion, %
1...	MC:S	1:3	0.08
2...	MC:S	1:3	0.10
3...	PC:L:S	1:1:6	0.13
5...	L:S	1:3	0.10
8...	L:S	1:3	no test
9...	MC:S ^a	1:1:6 ^a	4.6
10...	MC:S ^b	1:2:8 ^b	5.0
11...	PC:clay:sand	1:1:4-1/2	0.09
12...	PC:S + organic additive	1:3 + 15%	0.09

NOTE—MC = masonry cement,
 S = sand,
 PC = portland cement, and
 L = lime.

^a Masonry cement composed of portland cement and normally hydrated dolomitic lime; with sand it produces mortar of composition 1:1:6 PC:L:S.

^b Masonry cement composed of portland cement and normally hydrated dolomitic lime; with sand it produces mortar of composition 1:2:8 PC:L:S.

cements; two of them (in mortars Nos. 1 and 2) were of the portland cement: limestone type and their mortars were low in autoclave expansion, as shown in the table. The other two masonry cements (in mortars Nos. 9 and 10) were composed of portland cement and normally hydrated dolomitic lime blended together in such proportions that when these masonry cements were mixed with sand the resulting mortars were equivalent in volume proportions to 1:1:6 cement:lime:sand and 1:2:8 cement:lime:sand; these mortars were relatively high in autoclave expansion (approximately 5 percent), as indicated in the table.

Mortar No. 3, a cement:lime:sand mortar of volume proportions 1:1:6, was prepared from lime obtained as putty from the slaking of quicklime; this mortar was low in autoclave expansion. The same lime putty was used to prepare mortar No. 5, a lime:sand mix with no cement; the autoclave expansion of this mortar was also small. A second lime:sand mortar (No. 8) was prepared from normally hydrated dolomitic lime obtained from the plant which produced the masonry cement for mortars Nos. 9 and 10. Bars of this lime:sand mortar could not be prepared for autoclave tests because of the difficulty in de-moulding them.

Two additional mortars of small autoclave expansion were included in the study. Mortar No. 11 was composed of portland cement, a proprietary

clay material, and sand, while mortar No. 12 was prepared from portland cement and sand with a proprietary organic additive designed to produce high strength of bond between brick and mortar.

In addition to the bars for autoclave expansion tests, mortar bars were prepared for measurements of length changes. Some of them were stored in a room at 50 percent relative humidity and 73 F, while others were stored outdoors in a container with open sides but covered on top in such a way that the bars could not be wetted by rain or snow. All the mortar bars shrank under both storage conditions, the amount of shrinkage for each mortar being approximately the same. In six years the shrinkage among the various mortars varied from 0.07 to 0.20 percent.

Dimensional Changes of the Piers

Six years after their construction all the piers had expanded, as shown in the graphs of Fig. 2, which refer to the changes in the vertical dimension of the west walls of the piers. In a few cases, particularly piers of mortar No. 5, a lime:sand mortar, there was an initial vertical shrinkage of the brickwork which was recovered within the first year and was followed by expansion.

With the exception of the piers of mortars Nos. 8, 9, and 10, which contained normally hydrated dolomitic lime, the same general pattern of expansion took place and was generally of the same magnitude. The maximum vertical expansion of all these piers did not exceed 0.05 percent after six years. Much greater vertical expansion occurred in the piers of mortars Nos. 8, 9, and 10; the least vertical expansion was about 0.12 percent, while the maximum was about 0.48 percent.

Expansion of the piers in the horizontal direction was considerably less than that in the vertical direction. A comparison of the expansions in these two directions, given in Fig. 3, clearly shows the difference; the points plotted refer to the maximum amount of expansion, vertically and horizontally, that has taken place in each pier in the six years since its construction. In several cases the vertical expansion was three times as large as that which occurred in the horizontal direction; in one case it was more than five times as great.

Previous studies^{3, 4} have shown that a restraining force of small magnitude greatly affects the amount of expansion and shrinkage of masonry mortars. The difference in horizontal and vertical expansions of the brick piers can be attributed to the restraining effect of the bond between brick

³ Ritchie, T., "Effect of Restraining Forces on the Expansion of Masonry Mortars," *Materials Research & Standards*, Vol. 4, No. 1, Jan. 1964, pp. 15-19.

⁴ Ritchie, T., "Effect of Restraint on the Shrinkage of Masonry Mortars," *Materials Research & Standards*, Vol. 6, No. 1, Jan. 1966, pp. 13-16.

FIG. 2—Vertical movements of west walls of piers.

and mortar. Figure 4, which represents a vertical section through brick masonry, shows that each brick is bonded to the surrounding mortar. If the mortar of the horizontal joints attempts to expand it is restrained in the horizontal direction because of the bond with the brick, but it is not restrained in the vertical direction; the mortar of the horizontal joints, therefore, is free to expand vertically but not horizontally. The mortar of the vertical joints, similarly bonded to the brick, cannot expand in the vertical direction nor can it expand across the width of the joint as it cannot displace the bricks on either side of it because of their bond to the horizontal mortar joints.

The piers of mortars Nos. 8, 9, and 10 containing normally hydrated dolomitic lime expanded horizontally (as they had vertically) more than the piers of the other mortars. The maximum horizontal expansion of the piers of these three mortars was 0.114 percent in six years, whereas the maximum horizontal expansion of the other piers was only 0.056 percent. If, in order to allow for these maximum expansions of 0.114 and 0.056 percent in a wall, a vertical expansion joint of $\frac{1}{2}$ in. width was incor-

FIG. 3—Relationship between vertical and horizontal expansion (maximum values in six years).

FIG. 4—Influence of brick: mortar bond on vertical and horizontal expansion of mortar.

porated into the brickwork it is calculated that such a joint would have to be provided every 36 ft in the wall where the expansion was 0.114 percent, and every 74 ft in the wall where the expansion was 0.056 percent.

Influence of the Direction of Exposure on Expansion

Measurements of dimensional changes were made on the east- and west-facing walls of the piers, but as these walls were linked by short adjoining walls the movements of the one undoubtedly influenced the other. The expansions of the east- and west-facing walls of each pier (maximum amount measured in six years) are compared in Fig. 5; the scatter of results and the lack of any consistent pattern make it impossible to define the influence of direction of exposure on expansion.

Influence of the Brick on the Expansion of the Piers

The expansion which took place in the three bricks during their long-term storage indicated that the bricks would have an effect on the expansion of the piers. As the horizontal movement of a pier was probably more

influenced by the brick than its vertical movement, horizontal expansion was used in an attempt to determine the influence of the bricks on the expansion of the piers. The values of the maximum horizontal expansions measured in all the piers are plotted in Fig. 6 which illustrates eight groups of three piers, each group representing one of the mortars used with the three bricks. In an additional group (of mortar No. 2) only two bricks were used, and this group was not considered in regard to the bricks' influence on expansion.

FIG. 5—Comparisons of expansion of east and west walls.

FIG. 6—Influence of the brick on the horizontal expansion of the piers.

Figure 6 indicates that the influence of the brick was not consistent but appeared to depend on the direction of exposure of the wall. For the east-facing walls, in five of the eight groups of piers, the maximum expansion occurred in piers of Brick B, but for the west-facing walls, in seven of the eight groups of piers, the maximum expansion occurred in piers of Brick C.

Influence of a Structural Load on Expansion

When measurements of the piers indicated that larger vertical expansions were taking place in those piers of the three mortars containing normally hydrated dolomitic lime than in the others, additional piers were built with these mortars to determine the influence on their expansion of a load applied to them soon after construction. In this later study Brick A was used to construct six piers, two each of mortars Nos. 8, 9, and 10. One of the piers was unloaded (corresponding to the original piers), while the other had a vertically acting load applied to it that provided a pressure of 15 psi on the brickwork.

The load considerably reduced the vertical expansion as indicated by Fig. 7 which shows the vertical movements of the west wall of each of the

FIG. 7—Influence of load on vertical expansion of piers.

six piers in the three years after construction. The pressure on the brickwork had a different effect on various piers. The ratio of the amounts of expansion of the unloaded and loaded piers was about six for the pier of mortar No. 8 (composed of lime and sand), it was about three for the pier of mortar No. 10 (containing two parts lime to one part cement), and about two for the pier of mortar No. 9 (equal volumes of lime and cement).

The vertically applied pressure on the brickwork reduced the horizontal expansion (Fig. 8), but the effect was much less pronounced than for the vertical expansion.

Chemical Effects on Mortar Expansion

As the expansiveness of mortars containing normally hydrated dolomitic lime appears to be caused by their magnesia content and because magnesia reacts with chloride compounds to form magnesium oxychloride, a few tests were made to determine the effect of chloride additives in mortar on their expansion.

Certain bars of mortar No. 9, prepared from the masonry cement containing equal parts by volume of portland cement and lime, had an autoclave expansion of 2.5 percent. Companion bars, some made with magnesium chloride and others with calcium chloride dissolved in the mixing water in amounts of 4.8 and 5.5 percent of the weight of the masonry cement, had reduced autoclave expansions of 0.35 and 0.16 percent, respectively.

FIG. 8—Effect of load on horizontal and vertical expansions of piers.

Additional tests were made on brick piers, three of which (two of mortar No. 9 and one of mortar No. 10) were constructed of mortars containing calcium chloride and magnesium chloride additions. The vertical expansions of these piers are shown in Fig. 9 beside the expansions of piers of the same mortars without the additives. The values plotted represent the maximum expansions of the piers in three years.

Even though the autoclave expansion of mortar No. 9 was much reduced by additions of calcium and magnesium chlorides, the expansion of the piers of mortar No. 9 containing these additives was little reduced over that of the pier of the same mortar without the additives. The pier of mortar No. 10 containing calcium chloride, however, underwent much less expansion than its companion pier of the same mortar without the chloride additive.

Performance of Buildings

Examination of a number of buildings constructed of mortar containing normally hydrated dolomitic lime failed to reveal indications of masonry

FIG. 9.—Effect of chloride additions to mortar on vertical expansion of piers.

distress such as cracking, displacement, or bulging, any of which could be attributed to the expansion of the mortar. Some of the buildings examined were 30 years old.

Conclusions

Three mortars containing normally hydrated dolomitic lime, two of which were shown to be and the third assumed to be highly expansive on autoclaving, produced a greater amount of expansion of brickwork piers than six other mortars that expanded less on autoclaving.

The effect on the brickwork of the expansion of the three mortars was, to a considerable degree, directional in that the piers expanded more in the vertical direction than in the horizontal. This directional difference was attributed to the restraint on the horizontal but not vertical expansion of the horizontal mortar joints, the restraint resulting from the bond between the mortar and the brick. A load applied to the brickwork reduced the amount of expansion especially in the vertical direction; a relatively slight pressure (15 psi) was sufficient to reduce significantly the vertical expansion of the brickwork.

The results of this study, when applied to the practical situation of the brick masonry walls of buildings, appear to offer an explanation for the successful use of mortars containing normally hydrated dolomitic lime. Even though such mortars tend to expand in service, the resulting directional nature of the expansion and the fact that the expansion is inhibited by relatively slight loads on the brickwork renders the expansion non-damaging to the structure. It should be noted, too, that mortar alone does not determine the dimensional changes of brickwork; the three bricks used in constructing the piers of this study underwent long-term expansion and so must have contributed to the expansion of the piers.

The influence, if any, of the direction (east-west) of exposure of brick walls on their expansion was not established in this study because the piers were poorly designed to measure possible directional effect. The addition of calcium and magnesium chloride to mortars containing normally hydrated dolomitic lime reduced the expansion of the brickwork.

DISCUSSION

*Byron Powell*¹ (*written discussion*)—This paper adds to the results of the author's long term study of the effects of each of the components in masonry construction.

In prior papers the author has shown the effects of: (1) dimensional instability or unsoundness of the various brick units and mortars, (2) the effects of restraining forces on expansion of masonry mortars, and (3) the effect of restraining forces on shrinkage of masonry mortars.

In this paper the author concludes that mortars made with normal hydrated lime contribute to but are not totally responsible for expansion of brickwork. He further concludes that mortars containing normal hydrated lime show satisfactory performance in field use. Although reasonable explanations for this satisfactory performance are given, the question of whether normal hydrated lime should or should not be used in masonry mortar remains unanswered.

T. Ritchie (author's closure)—The question of whether normally hydrated dolomitic lime should be used in masonry mortar has been answered if one accepts what must be the final criterion of assessment, its satisfactory long-term performance in buildings, which was reported to be the case for the limes of Toronto, Ontario. The results of the paper merely provide, as Mr. Powell states, reasonable explanations for this satisfactory performance, in spite of potential expansions of mortars and bricks which theoretically must produce cracking of a wall. Whether differences in dolomitic limes and in building practices between those of Toronto and of other areas would result in a difference in the performance of buildings is not known, but it is considered unlikely to be the case.

This study has indicated what is generally well recognized, that it is extremely difficult to predict the behavior of brickwork from a study of the properties of the individual bricks and mortar, and when the brickwork serves as part of a building there are additional complications in the prediction of its performance.

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