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INFLUENCE OF MORTAR COMPOSITION ON RESISTANCE TO MOISTURE PENETRATION AND STRENGTH OF MASONRY

by

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PREFACE

The studies of resistance to rain penetration and bond strength of unit masonry carried out in the Division's laboratories have employed both small panels consisting of five bricks in stack bond and wall panels $3\frac{1}{2}$ by 4 ft. The cost of the larger panels limits the number which can be made for testing, but they are more representative of full-scale walls, particularly since they are always made by a bricklayer whereas the small panels are not. A series of tests designed to evaluate certain bricks and mortars were carried out using the larger wall panels and the results are now reported.

The author, a research officer in the Building Materials Section of the Division is responsible for the brick masonry studies carried out at the laboratories in Ottawa.

Ottawa
June 1962

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INFLUENCE OF MORTAR COMPOSITION ON RESISTANCE TO MOISTURE PENETRATION AND STRENGTH OF MASONRY

by

T. Ritchie

The effects of changing the composition of mortar on the properties of brickwork have been described in several reports of the Division of Building Research. Much information on the subject is available, based on numerous studies carried out by many research organizations. As a continuation of DBR's investigations in this field, a number of test walls were constructed to determine the effect of changing the composition of mortar on the properties of resistance to moisture penetration and transverse strength.

The mortars used varied over a wide range in composition, including lime:sand, cement:lime:sand and masonry cement : sand mixes. In addition, mortar containing a proprietary material to replace lime was studied. The material, which was developed in the Toronto area a number of years ago, and which has been used extensively in recent years in that area and elsewhere for brick and block construction, is essentially finely ground shale, marketed as a dry powder in 50-lb bags of 1-cu ft capacity. To prepare mortar it is mixed with portland cement, sand and water. The use of such material in mortar has been reviewed in detail (1) and reference has been made to early Canadian studies (2) of the subject.

SCOPE

Five mortars with three bricks were used to make 25 test walls which were built by a qualified bricklayer. The walls were about 3½ ft wide by 4 ft high. After construction they were stored for one month, then were tested for resistance to moisture penetration by the method described previously (3); an air pressure difference of 2 in. of water across the wall was used. After the moisture penetration test the wall was stored for two months, and then tested for transverse strength. In this test two horizontal bars, 44 in. apart, were placed against the back of the wall, and another bar mid-way between them was placed against the front surface of the wall. Force was applied through this bar by means of a hydraulic jack and the load required to break the wall was recorded.

MATERIALS

(a) Mortars

A lime:sand mortar, two cement:lime mortars and a masonry cement mortar were used, besides those containing the shale plasticizer. For each of the first four mortars, two ratios of cementing material to sand were used -- 1:2½ and 1:3 by volume. The sand was a well-graded natural sand. The lime was a dry hydrate which was soaked in water overnight before use, and proportioned on the basis of the volume of the paste. The materials were mixed by hoe in a mortar trough by the bricklayer's helper who brought the mortar to a consistency which the bricklayer considered suitable.

On the recommendation of the supplier of the proprietary material the mortar containing it was mixed in proportions by volume of one part portland cement, one part material and four and one-half parts of sand. According to the supplier, several suitable mixes can be prepared from the material to produce mortars that cover a range of compressive strengths of the mortar. Each mix corresponds by strength to one of the types of mortar given in ASTM specification C270-54T, "Mortar for Unit Masonry." Thus the 1:1:4½ mix was said to produce a mortar of ASTM type "S".

For each batch of mortar prepared during the construction of the walls, a sample of mortar was taken and its flow was measured. In many cases the flow exceeded the capacity of the table (exceeded 150 per cent). The flow after suction was measured again and the water retention value was obtained (ratio of flow after suction to original flow). A wide variation in flow and in water retention value was frequently noted in batches of mortar of the same composition. The mortars used in the study with the corresponding minimum and maximum flow values are listed in Table I. The range of retention value for each mortar is also given. The relatively high flows of the mortars are evident in the Table; for all mortars except one there was at least one batch of mortar with flow greater than 150 per cent, and for one mortar there was no sample of flow less than 150 per cent.

(b) Bricks

Two bricks, one moderate in suction and the other high in suction, were used with each of the mortars listed in Table I. A third brick, high in suction, was used with cement:lime, masonry cement and lime mortars. The brick of moderate suction (14.0 to 23.5 gm/min/30 sq in.) had been made by the extrusion method. It was smooth-faced and red, with three core holes. The first high-suction brick had been made by the dry-press method; it was yellow, smooth-faced and had three core holes. The suction ranged from 66.0 to 109.5 gm. The other high-suction brick had been made by the extrusion method. Its suction ranged from 63.3 to 81.2 gm. These bricks were also yellow and cored with three holes.

The properties of the bricks are shown in Table II; the range in values given is for 20 samples tested, except for the compressive strength test in which five samples were used. The bricks were used dry in constructing the test walls. Samples of the bricks were tested frequently during the construction of the walls to determine the moisture content; in all cases it was a fraction of one per cent of the dry weight.

TEST WALLS

The walls were five bricks wide and 19 courses high (about $3\frac{1}{2}$ by 4 ft). The thickness was one brick, about 8 3/8 in. Common bond pattern was used, consisting of five courses of stretcher bricks between courses of header bricks. The mortar joints of the "exterior" surface of the wall were concave-tooled.

RESULTS

The results of the tests are presented in Table III. The information obtained from the moisture penetration tests is listed for each wall, including the time taken for dampness to appear on the back of the wall after the start of the test, the time taken for water to start dripping from the back of the wall, the total amount of water (in ml) which leaked through the wall in 24 hr of test, and the maximum rate of leakage (ml per min) of water from the back of the wall. The load in pounds required to break the wall transversely is shown, along with the modulus of rupture (psi) calculated from the breaking load.

RESISTANCE TO MOISTURE PENETRATION

The results given in Table III show that the wall of each of the three bricks which was most resistant to moisture penetration contained lime:sand mortar. Walls of the two high-suction bricks were considerably less resistant to moisture penetration than those of the moderate-suction brick. It is of interest, however, that even though the dry-press brick was slightly higher in suction than the high-suction extruded brick, nevertheless walls of the former brick performed better than those of the extruded brick. The planeness of the surfaces of the pressed bricks, by favouring better establishment of bond with the mortar, may have accounted for the difference.

The walls of the moderate-suction brick and the mortar containing shale plasticizer appeared to perform slightly better in the moisture penetration test than those of 1:1:5 and 1:1:6 mortar. In the moisture penetration test, however, walls of the shale plasticizer mortar with the dry-press brick were superior to all other walls of this brick except those with lime:sand mortar.

The effect of changing the ratio of cementing material to sand from 1:3 to 1:2½ was not consistent. In some cases slight improvement apparently resulted from the richer mix, but in others the reverse occurred. Duplicate walls of the moderate-suction brick with the mortar containing shale plasticizer differed considerably in performance, but the duplicates of walls of this mortar with the dry-press brick were much more consistent in results. Nevertheless, the effect of changing the variables of the richness of the mix, the mortar composition and the type of brick, was undoubtedly masked to some extent by the low order of the reproducibility of results.

TRANSVERSE STRENGTH

The weakest wall in transverse strength of each of the three bricks contained lime:sand mortar. The influence of the mortar composition on the transverse strength of masonry was most marked in the walls of moderate-suction brick. For these walls the breaking load varied from 460 to 7150 lb; the corresponding modulus of rupture varied from less than 10 psi to more than 153 psi. The influence of mortar composition on the strength of the masonry was much less pronounced for walls of the two high-suction bricks.

Walls of the shale plasticizer mortar and the moderate-suction brick were slightly weaker than that of the 1:1:6 mortar, which was the strongest of all the walls tested. The strongest walls of dry-press brick contained mortar of shale plasticizer. This wall was slightly stronger than the wall of 1:1:5 mortar, but the duplicate wall was weaker than the cement:lime mix.

CONCLUSIONS

The composition of mortars considerably affected the resistance of brick masonry to moisture penetration and its transverse strength. For the walls tested in this study, these two properties appeared to be incompatible in that walls of lowest strength were highest in resistance to moisture penetration.

Mortar containing a proprietary shale material to replace lime was considered to have produced masonry not significantly different from that of 1:1:6 cement:lime mortar.

The variation in the ratio of the cementing material to sand in the mortars did not have a consistent effect on the properties of the brickwork. The reproducibility of results in the series of tests was not considered to be of a high order.

The results of the tests confirmed previous observations that the properties of the brick used have a significant effect on the properties of the brickwork.

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TABLE I

COMPOSITION, FLOW, AND WATER RETENTION VALUE OF MORTARS

Mortar composition (*)	Flow of mortar as used in wall construction (per cent)		Water retention value of mortar	
	Min	Max	Min	Max
1:2½ L:S	117	150 +	79.8	86.2
1:3 L:S	116	150 +	80.1	86.8
1:2:7½ C:L:S	130	142	81.9	86.1
1:2:9 C:L:S	150 +	150 +	-	-
1:1:5 C:L:S	120	150 +	72.8	79.7
1:1:6 C:L:S	127	150 +	75.7 (**)	75.7
1:2½ MC:S	115	150 +	66.0	79.9
1:3 MC:S	129	150 +	71.5	75.1
1:1:4½ C:SH:S	115	150 +	70.2	86.5

(*) L = lime S = sand C = portland cement
MC = masonry cement SH = proprietary shale plasticizer

(**) one sample of mortar tested; all others were of flow greater than 150 per cent.

TABLE II

PROPERTIES OF BRICKS

Property	Moderate-suction brick	Dry-press brick	High-suction extruded brick
Suction (g/min/30 sq in.)	14.0 - 23.5	66.0 - 109.5	63.3 - 81.2
Absorption on immersion			
(per cent dry wt) 24 hr	7.7 - 9.4	16.5 - 20.4	15.8 - 20.1
5 hr boiling	9.2 - 10.9	20.1 - 24.0	17.7 - 22.5
Saturation coefficient	0.82 - 0.87	0.84 - 0.85	0.88 - 0.90
Bulk density (g/cc)	2.07 - 2.12	1.68 - 1.79	1.72 - 1.81
Compressive strength (psi)	12,600	5,170	7,840

TABLE III

RESULTS OF TESTS

Mortar composition	Time from start of test: For first dampness to appear, Hr	Min	For first leakage from back, Hr	Min	Total leakage (ml/24 hr)	Maximum rate of leakage (ml/min)	Load to break wall (lb)	Modulus of rupture (psi)
Moderate-Suction Extruded Brick								
1:3 L:S	2	30	2	35	31,800	29	460	9.9
1:2:9 C:L:S		20	4	30	760	0.7	4460	96.0
1:1:6 C:L:S		28	6	30	17,735	23	7150	153.9
1:3 MC:S		1		20	24,650	33	1370	29.5
1:2½ L:S	2	30	5	30 +	131	0.6	480	10.3
1:2:7½ C:L:S		58	4	50	15,285(**)	15	4260	91.7
1:1:5 C:L:S		11	2	15	45,750	43	4320	93.0
1:2½ MC:S		7		10	52,030	45	2010	43.2
1:1:4½ C:SH:S		15	1		16,200	12	5800	124.8
1:1:4½ C:SH:S	1	15	3		6,090	8	6700	144.2
High-Suction Dry-Press Brick								
1:3 L:S	1	35	6	30 +	30,000	41	210	4.5
1:2:9 C:L:S		30	1	18	184,000	169	260	5.6
1:1:6 C:L:S		9		45	263,000	372	600	12.9
1:3 MC:S		5		50	210,760	186	720	15.5
1:2½ L:S	1	50	7	15	31,505	34	305	6.6
1:2:7½ C:L:S		50	1	30	122,690	108	660	14.2
1:1:5 C:L:S		24	1	5	151,000	131	1420	30.6
1:2½ MC:S		2		40	262,820	228	440	9.5
1:1:4½ C:SH:S	1	5	3	15	81,770	83	1710	36.8
1:1:4½ C:SH:S		40	2	40	68,910	63	1010	21.7
High-Suction Extruded Brick								
1:1:6 C:L:S		20		45	320,020	325	520	11.2
1:3 MC:S		12		15	509,590	460	700	15.0
1:2½ L:S		30		50	157,620	170	460	9.9
1:1:5 C:L:S		15	1	10	288,980	246	830	17.9
1:2½ MC:S		13		21	411,670	344	730	15.7

(*) L = lime S = sand C = portland cement MC = masonry cement
SH = proprietary shale plasticizer

(**) one area only of this wall was damp in 24 hr of test and the leakage occurred in this one area.

(+) leakage occurred after the time listed; exact time not known.