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EFFECTS OF FREEZING BRICK MASONRY AT AN EARLY AGE

by

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PREFACE

The promotion of winter construction in Canada as an aid in reducing winter unemployment in the construction industry has led to a need for a reassessment of the cold weather protection required during the laying of masonry. The Division, recognizing this need, has constructed a cold room and has initiated a program of study of the effects of freezing, under various conditions, upon newly laid brick masonry.

P. T. Hodgins, the second author, and a research officer with the Building Materials Section, was in charge of the first phase of the study. This report of the work which was carried out by Mr. Hodgins before he left the Division to take up other duties, has been prepared by Mr. Ritchie, a ceramic engineer and a research officer with the Division who has been engaged for many years in studies of brick masonry. The results reported are preliminary only, since it has not yet been possible to resume work on the project.

Ottawa — N. B. Hutcheon

March 1961 — Assistant Director

EFFECTS OF FREEZING BRICK MASONRY AT AN EARLY AGE

By T. Ritchie and P. T. Hodgins

Building construction in Canada is carried out year-round, although there is usually a slackening of activity in the winter season. During periods of severe cold, some types of work may be completely stopped unless protection is provided for the work or the workers or both. In many cities (for example, Ottawa) bricklaying has been carried out in air temperatures well below freezing without protection to the work. The limiting consideration in many cases appears to be the capacity of the bricklayers to work in severely cold conditions, rather than possible impairment of the quality of the work.

To prevent reduction in the quality of masonry due to freezing at an early age, many specifications and codes of practice for brick masonry construction require that the temperature of the masonry be maintained above freezing for some time (usually at least 48 hours) after the brickwork is constructed to permit it to achieve resistance to damage before being frozen. Many contractors however, have noted that brick masonry which had been constructed without protection in very cold weather apparently has performed satisfactorily. The need for the requirements set out in specifications regarding protection to the masonry during construction in freezing weather has therefore been questioned, and it seems important to determine how the properties of brick masonry constructed under freezing conditions differ from those of similar masonry constructed under normal (i.e. summer) conditions.

Preliminary laboratory studies of this problem were undertaken in the Division of Building Research in 1958. It was then planned to study small panels of brick masonry to determine the effect on various properties of freezing at an early age. The properties to be studied were resistance to moisture penetration, strength of bond between brick and mortar, and dimensional changes in the brickwork. It was originally planned that panels made of several types of bricks and several mortar compositions would be studied. The bricks were to be chosen to cover a wide range of initial rate of absorption, or "suction", which is an important property with respect to the bonding between brick and mortar. The first part of the study involved the construction of panels using a low-suction brick and a variety of mortars. When this part of the work was completed, however, the research officer supervising the study left the Division for other duties, with the result that the program originally planned has not yet been completed. The results presented in this report therefore refer only to the particular low-suction brick used, and it is considered likely that different results will be obtained when other types of bricks are employed.

TEST PANELS

The panels consisted of five bricks laid one above the other with mortar joints between, assembled and tested for moisture penetration and bond strength properties as described in DBR Internal Reports Nos. 160 and 175 (1,2). The time interval between placing the mortar on the surface of the brick and then placing the next brick on it was set at 30 seconds, and a tapping impact of 4 pounds dropping through $1\frac{1}{2}$ inches was used to bed the brick in the mortar. The top and bottom bricks of each panel, prior to panel construction, were fitted with brass pins used to measure changes in the panel height. A micrometer head which gave readings to 0.0001 inch was used for measuring the dimensional changes.

CONDITIONS OF CONSTRUCTION

Panels were assembled under three conditions:

(a) The bricks and the freshly mixed mortar, both at a temperature of 73°F, were assembled into panels in a room at 73°F, and remained at that temperature until tested.

(b) Bricks and freshly mixed mortar, both at a temperature of 73°F were taken into a cold room maintained at 0°F and immediately made into panels.

(c) Freshly mixed mortar at a temperature of 73°F and bricks at a temperature of 0°F were assembled into panels in a cold room maintained at 0°F.

The second situation (b) was intended to correspond to the practice of providing heated bricks and mortar to the bricklayer; the brickwork after construction was unprotected and cooled below the freezing point. The third condition (c) was intended to correspond to the practice of using warm mortar with cold bricks and the masonry left unprotected and cooled below the freezing point. The difference between conditions (b) and (c) is essentially in the rate of freezing of the mortar; the warm brick of condition (b) would produce a slower rate of cooling of the mortar, compared with that of the mortar laid in contact with the cold brick condition (c).

It was considered that any damage to brickwork as a result of freezing would be more severe if earlier freezing of the fresh mortar took place, and for this reason no study was made of the effects of freezing brickwork which had been aged for a considerable length of time at above-freezing temperature. Also, the effect of alternate freezing and thawing was not investigated.

For the panels constructed under "normal" conditions (73°F) the procedure adopted was to store the completed panel in a plastic cover for 24 hours, then place the uncovered panel in a high-humidity chamber (73°F and 100 per cent R.H.) for 6 days. It was then removed from the chamber and tested for moisture penetration. Afterwards, the panel was placed in a room at 73°F, 50 per cent R.H., until age 14 days when the bond strength test was made.

The panels which were constructed in the cold room were left there for 24 hours. On removal they were placed in the high-humidity chamber (73°F and 100 per cent R.H.) for 7 days and the moisture penetration test was then made. After this test there was a period of storage at 73°F and 50 per cent R.H. until the panel was 15 days old, when the bond strength was determined.

Some panels were made of lime mortar, in which case they were stored after construction for 14 days in a room at 73°F and 50 per cent R.H. (rather than 7 days at 100 per cent humidity as for the other panels), and at age 14 days the moisture penetration test was made. The bond strength test of panels of lime mortar was made at age 28 days (instead of 14 days as for the other panels).

BRICKS

One type of brick was used, a dense, low-suction red brick made by the extrusion process. The initial rate of absorption was in the range 1 to 5 grams per minute per 30 square inches. The bricks contained 10 core holes, arranged in two rows, and the surfaces of the bricks were smooth, not textured.

MORTARS

Lime, portland cement, mixtures of lime and portland cement, and two types of masonry cement were used with sand to prepare mortar. The ratio by volume of cementing material to sand was 1:3, except for one of the masonry cements which in accordance with the manufacturer's recommendation was proportioned with sand in the ratio 1:2-2/3. One masonry cement was an interground mixture of portland cement and limestone, while the other was a blend of portland cement and hydrated lime.

One of the cement:lime mortars was composed of one part by volume of well-aged lime putty, two parts of portland cement and nine volumes of sand, while the other cement:lime mortar contained two parts of lime, one part of portland cement and nine parts of sand.

The mortars were used in two consistencies of 115 per cent and 125 per cent flow as measured by the flow table. Highly variable flow values of duplicate batches of the same mortar, however, were frequently noted.

RESULTS

The results obtained from the tests are summarized in Table I. The composition of the mortar used in the panel and its flow, the conditions under which the panel was constructed, the dimensional changes which occurred, the total amount of leakage which took place in 24 hours of test for moisture penetration, and the average bond strength of the four mortar joints of the panel, are shown.

DIMENSIONAL CHANGES

When bricks and mortar were assembled under "normal" conditions (in a room at 73°F) and were maintained at this temperature until the tests were made, in all cases shrinkage of the panel took place. Most of the movement took place in the first 7 days (i.e. up to the time of the leakage test). In the next 7 days (up to the time of the bond strength test) there was little additional shrinkage. The flow (wetness) of the mortar did not appear to influence greatly the amount of shrinkage. The maximum shrinkage was slightly less than 0.007 inch, in an effective panel height of about 11 inches, or about 0.06 per cent.

When the bricks and mortar were assembled in the cold room, however, the dimensional changes were quite different from those of panels assembled under "normal" conditions. Instead of shrinkage, expansion occurred during the freezing of the panels. When the panels were thawed (after 24 hours in the cold room), a pronounced shrinkage took place. This "thawing shrinkage" in some cases exceeded the initial "freezing expansion" and in other cases was less than the expansion, so that a net movement in the panel from the freezing and thawing resulted. The "freezing and thawing" movements were appreciably greater in extent than the "normal" shrinkage of unfrozen panels.

The difference in results between panels made of cold bricks and those made of warm bricks (in both cases assembled in the cold room) appeared to be in the rate of freezing, and it appeared that with the cold bricks the mortar of the bottom joints of the panel was frozen before the panel was completed, and for these joints therefore the "freezing expansion" had taken place before measurement of panel height was made.

After the bond strength tests were made, distinctive "crow's-feet" crystal patterns were observed at the brick-mortar interface of many of the panels which had been frozen. There seems little doubt that the "freezing expansion" was due to the formation of ice crystals in the mortar, or between mortar and brick, and the patterns of the crystals remained after thawing.

MOISTURE PENETRATION

As shown in Table I, only those panels of the two masonry cements had no leakage through the panel in the 24 hours of test when constructed under "normal" as well as under early-freezing conditions. The resistance to moisture penetration of these panels therefore, apparently was not influenced by early freezing. In all other cases however, the construction of the panels in the cold room had an adverse effect on resistance to moisture penetration. For example, panels of the portland cement and sand mortar and of the cement-lime mortars (1:2:9 cement:lime:sand and 2:1:9 cement:lime:sand) when constructed under "normal" conditions had no leakage of water in 24 hours of test, but when constructed in the cold room, however, there was leakage through the panels in the moisture penetration test. The early freezing of these panels, therefore, resulted in more permeable brickwork. Similarly, the panels of the lime:sand mortar constructed under "normal" conditions allowed appreciable moisture penetration in the 24 hours of test, and the amount of leakage was greatly increased when the panels were constructed in the cold room.

BOND STRENGTH

Panels of all mortars had lower bond strength when constructed in the cold room compared with similar panels constructed under "normal" conditions. In most cases the reduction in strength was appreciable. For example, panels of the 1:2:9 cement:lime:sand mortar had an average bond strength of about 12.5 p.s.i. when constructed under "normal" conditions, but only about half this value under cold room construction. Similarly, for panels of the 2:1:9 cement:lime:sand mortar, the "normal" bond strength was over 30 p.s.i. but this was reduced to about 21 p.s.i. for cold room construction with warm bricks, and to about 16 p.s.i. for cold room construction with cold bricks. For several of the panels subjected to early freezing the bond strength was considerably less when cold bricks were used than warm bricks. It is clear from the results shown in Table I that early freezing of the panels resulted in considerably lower strength of bond than that obtained from "normal" construction.

BOND STRENGTH OF FROZEN BRICKWORK

Even though the bond strength of panels which were frozen then thawed was less than that of similar panels which had not been frozen, it was found that while a panel remained frozen it had appreciable strength of bond. This was determined by making a test for bond strength while a panel was in the frozen state. The bond strength thus measured was over 70 p.s.i., compared with less than 12 p.s.i. for similar brick and mortar assembled without subsequent freezing. It appears that ice may form a cementing material between the bricks, adding to the strength of the assemblage as long as it remains as ice.

COMPRESSIVE STRENGTH OF FROZEN MORTAR

A few tests were made using 2-inch cubes of a masonry cement mortar to investigate the effect of early freezing of the fresh mortar on its compressive strength. No appreciable difference in compressive strength was noted however when cubes were made and stored under "normal" (73°F) conditions and when similar cubes were frozen at an early age then thawed and subsequently tested. The compressive strength of mortar cubes which had been frozen, and tested while still frozen, slightly exceeded the compressive strength of "normal" mortar cubes indicating that the presence of ice in the mortar contributes to the compressive strength as long as it remains as ice.

SUMMARY

The effect of early freezing of brick masonry panels on dimensional changes, bond strength and resistance to moisture penetration was studied. The investigation was restricted to the use of a low suction brick with mortars of several compositions.

Panels constructed without subsequent freezing shrank, while those which were constructed in a cold room expanded, and subsequently shrank on thawing. The strength of bond between brick and mortar in all cases was reduced as a result of the early freezing, when compared with the bond strength of similar panels which had not been frozen. The effect of early freezing on resistance to moisture penetration was variable; some panels were free of leakage under both "normal" and "early freezing" conditions of construction, while others were leak-free under "normal" conditions but were permeable when built under freezing conditions. Early freezing of brick masonry of the materials used therefore significantly affected the properties of the brickwork; the formation of ice crystals at the brick-mortar interface and in the mortar was observed.

The strength of bond, and compressive strength, of brickwork while still in the frozen state was indicated to be higher than that of unfrozen brickwork, the ice apparently acting as a cementing agent.

REFERENCES

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TABLE I

RESULTS OF TESTS

MORTAR COMPOSITION	MORTAR FLOW	CONDITION OF CONSTRUCTION (*)	DIMENSIONAL CHANGE (INCHES)(**)			TOTAL LEAKAGE 24 HRS. (ml.)	AVERAGE BOND STRENGTH (p.s.i.)
			NORMAL CONSTRUCTION	ON FREEZING	ON THAWING		
1:3 Lime: Sand	125	Normal	-0.0065			443	1.3
"	115	Normal	-0.0056			527	1.5
"	125	Cold Room - Warm Bricks		+0.0136	-0.0247	no test	0
"	115	Cold Room - Warm Bricks		+0.0210	-0.0240	3035	0
"	125	Cold Room - Cold Bricks		+0.0003	-0.0562	4450	0
"	115	Cold Room - Cold Bricks		no test	no test	no test	0
1:2:9 Cement: Lime: Sand	125	Normal	-0.0033			0	12.8
"	115	Normal	-0.0025			0	12.9
"	125	Cold Room - Warm Bricks		+0.0137	-0.0130	184	6.8
"	115	Cold Room - Warm Bricks		+0.0209	-0.0150	350	6.2
"	125	Cold Room - Cold Bricks		+0.0019	-0.0165	78	6.1
"	115	Cold Room - Cold Bricks		+0.0027	-0.0175	161	6.6
2:1:9 Cement: Lime: Sand	125	Normal	-0.0024			0	36.6
"	115	Normal	-0.0017			0	31.3
"	125	Cold Room - Warm Bricks		+0.0168	-0.0082	217	20.2
"	115	Cold Room - Warm Bricks		+0.0183	-0.0078	42	22.5
"	125	Cold Room - Cold Bricks		no test	-0.0062	8	17.8
"	115	Cold Room - Cold Bricks		+0.0018	-0.0081	72	14.4
1:3 Portland Cement: Sand	115	Normal	-0.0005			0	45.2
"	115	Cold Room - Warm Bricks		+0.0145	-0.0077	120	13.1
"	115	Cold Room - Cold Bricks		+0.0057	-0.0150	128	10.9
1:3 Masonry Cement: Sand	125	Normal	-0.0010			0	31.7
"	115	Normal	-0.0014			0	22.2
"	125	Cold Room - Warm Bricks		+0.0034	-0.0043	0	10.6
"	115	Cold Room - Warm Bricks		+0.0058	-0.0048	0	14.4
"	125	Cold Room - Cold Bricks		no test	-0.0129	0	17.5
"	115	Cold Room - Cold Bricks		-0.0010	-0.0156	0	14.9
1:2 2/3 Masonry Cement: Sand	125	Normal	-0.0035			0	10.4
"	115	Normal	-0.0038			0	6.7
"	125	Cold Room - Warm Bricks		+0.0140	-0.0173	0	6.9
"	115	Cold Room - Warm Bricks		+0.0020	-0.0039	0	1.3
"	125	Cold Room - Cold Bricks		no test	-0.0168	0	3.4
"	115	Cold Room - Cold Bricks		no test	-0.0188	0	2.2

(*) Normal = Materials at 73°F constructed and maintained at temp. of 73°F.

Cold Room - Warm Bricks = bricks and mortar at 73°F brought into cold-room for assembly.

Cold Room - Cold Bricks = bricks at cold-room temperature and mortar at 73°F assembled in cold room.

(**) Minus sign indicates shrinkage
Plus sign indicates expansion