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Freeze-thaw Testing of Vertical Mortar Joints used in Horizontal Projections (Capstones, Plinth Stones and Window Sills)

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ABSTRACT

Horizontal surfaces of masonry courses such as capstones, plinth stones and window sills are subjected to severe exposure conditions as they frequently project beyond the plane of the building and act as drip surfaces. The design and construction of durable vertical mortar joints therefore, presents major challenges to any masonry restoration project. Vertical joints were examined in the laboratory as part of a larger mortar research program investigating performance criteria for restoration mortars to be used on the Parliamentary buildings in Ottawa, Canada. Three configurations were tested, representing cap stones, plinth stones and window sills. The joints were filled with mortar only, or also included a foam backer rod with sealant. Mortar mixes with masonry cement & type N hydrated lime, Portland cement & type S lime, and Portland cement & calcitic (high-calcium) lime putty were used. Testing focused on frost durability using a unidirectional freeze-thaw cabinet.

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INTRODUCTION

The Canadian Parliament buildings are undergoing major restoration. These building, built during the period of 1840 to 1930, have stone masonry exterior walls. A large component of the work will be repair and repointing of the stone masonry. Given the scale of the job, the Heritage Conservation Program (Public Works and Government Services Canada) determined that durability testing of the repointing mortar would be appropriate. The Heritage Conservation Program, the Institute for Research in Construction at the National Research Council Canada, and Suter Consultants Inc jointly conducted a research program to look at this. Other results from this program have been reported (1,2,3,4).

The architectural style of the buildings is Gothic. The horizontal projections of masonry courses, including capstones, plinth stones and window sills are carved. While Nepean sandstone makes constitutes the walls of the building, Ohio sandstone, a much softer stone, for carving, was used for the ornamentation.

These horizontal projections shed a large proportion of the water. Masonry constituents, mortar and stone, are porous making them potentially vulnerable to freeze-thaw damage. The design and construction of durable vertical mortar joints therefore, presents a major challenge to any masonry restoration project. Traditionally lead capping was used to shield vertical joints; however, there is no evidence of its use.

The objective of this paper is to discuss:

- the test procedure developed to investigate the freeze-thaw durability of masonry with vertical joints,
- the results of freeze-thaw testing, and
- the effect of freeze-thaw durability on joint configuration.

TEST SPECIMENS AND PROCEDURES

Specimen Preparation, Curing and Testing

Three shapes of Ohio sandstone were used to construct specimens for the freeze-thaw durability test. The shapes were intended to represent capstone, plinth stone and window sill (Fig. 1). A skilled mason built the specimens using a wooden jig to hold the stones in place during construction (Fig. 1). The mortar was compacted between the stones, building up the joint in several lifts. The jig restrained the stones, allowing the mason to apply pressure to the joint to ensure complete packing.

Two types of joint configurations were constructed, one with only mortar in the joint and the other also containing a foam backer rod/sealant. The sealant was meant to restrict water penetration into the joint. The mortar only joint was filled using mortar from one batch. The foam backer rod/sealant joint was constructed using two batches of mortar. The first batch was used to fill the joint approximately half way. This was allowed to cure under laboratory conditions for twenty-four hours. A 15 mm foam backer rod was then fitted into the joint and covered with a Sonolastic NP-2, two-component polyurethane sealant. The sealant was allowed to cure for an additional twenty-four hours. The remaining 10 to 20 mm of the joint was filled with a second batch of mortar.

Two types of masonry prisms were built for flexural bond strength testing (6 stone high). The stones were square, 90 x 90 mm, with a depth of 30 mm. One type of prism was stacked bonded with horizontal mortar joints, buttering the stones with mortar before placement. The second type of prism was built with the mortar joints vertical. Stones were placed in a wooden jig with 5-7 mm wooden spacers to ensure even spacing for the mortar joints. The five joints were packed in sequence, placing a lift of mortar in all the joints, repeating until finished.

Three, 50 mm (2 inch) mortar cubes were made for each of the mortar batches. These were de-molded after twenty-four hours.

All the test specimens were kept moist for the first seven days by enclosing them in polyethylene sheeting and placing wet rags within the enclosure. The specimens were then cured under laboratory conditions until the testing time of 28 and 90 days (relative humidity 55 ± 5%; temperature of 22 ± 2 °C).

The freeze-thaw specimens and the flexural bond specimens with vertical joints remained in the wooden jigs for the duration of curing. The decision to keep the specimens in the jigs was based on the following two reasons. First, there was concern that removing the specimens too early would put undo stress on the mortar bond. Second, it was thought that this would more closely represent differential curing of the mortar, from the front and back, which occurs in practice.

Mix Design and Properties

Three mortar mixes based on an earlier phase of testing (3) were used (Table 1). The masonry cement-type N hydrated lime, and the cement-lime putty mixes contained air entraining agents. The Portland cement-type S lime did not. The use of brick dust and crushed brick represented an early, albeit, naive investigation of these products in mortar (the crushed brick was introduced to entrain air, while the brick dust was added for its pozzolanic action; the use of brick to entrain air does not work). The lime putty was high calcium. Mix proportions were based on dry sand. An effort was made to keep the different batches of mortar similar. The water/binder ratio and flow table values were kept fairly constant.

Freeze-Thaw Durability Testing

IRC/NRC is in the unique position of having a Dutch developed freeze-thaw cabinet which conforms to the Dutch standard NEN 2872 for unidirectional freeze-thaw testing (6). For tests in this paper, the machine was modified to accept free standing wallettes, and sprinkler pipes were installed to wet the specimens during the thaw cycle.

In order to quantify the degree of damage, expansion across the mortar joint was measured. Measuring discs were glued to the face of the wallettes (Fig 2). The stainless steel discs are 6 mm in diameter with a drilled hole in the center, which is used to seat the conical point of a Demec gauge (Fig. 3). Measurements were taken across the mortar joints using a 50 mm gauge. On a couple of specimens, discs were placed on the stone itself. There was insignificant movement associated with the stone during the freeze-thaw tests. Therefore, for measurements across the mortar joints, all the change was assumed to be associated with movement in the joint.

The specimens were placed in the cabinet and completely immersed in water for twenty-four hours. The backs and sides of the specimens were then jacketed with 10 mm extruded polystyrene (Fig. 2). The edges were sealed with silicone, which was allowed to cure for 12 hours. During this curing period the specimens were kept at 100% relative humidity.

Flexural Bond Strength Tests

The flexural bond strength of the prisms was tested using a bond wrench based on ASTM 1072 (5). A total of five joints were tested for each prism. In cases where the joint was unable to accommodate the load of the test arm, a bond strength of 0.03 MPa was assigned. The results are presented in Table 2.

A rapid freeze cycle was used to test the specimens. It was considered representative of the damaging winter conditions experienced in Ottawa. Figure 3 shows a typical profile of the freeze-thaw cycle. Thermocouples were imbedded during construction within 5 mm of the face and back of the wallettes. The front of the specimen follows much the same temperature profile as that of the air temperature, showing a 10 minute lag. The back of the specimen shows a plateau in the temperature profile at 0°C, which occurs during freezing of water. The freezing front moves from the face of the wallette through 90 mm in approximately 2 hours. The thaw cycle is accelerated by spraying the specimens with water as soon as the air temperature rose above 0°C. The spraying lasts for the complete 2 hours of the thaw cycle, ensuring that the specimens do not loose any moisture (there may be a small gain in moisture).

The specimens were measured and assessed on every seventh day. After six days of freeze thaw cycling was completed (18 cycles), the specimens were conditioned for 12 hours by immersing them in water and then drained for 2 hours under conditions of 95% relative humidity. The joints were then measured and the cycling process recommenced 24 hours after the completion of the last cycle.

A damage rating was assigned to the joint at each measurement period. Table 3 is a summary of the designations. Visual assessment of damage was recorded for each measurement period.

The number of cycles varied depending on the durability of the specimen. Where the deterioration of the specimen was severe, it was removed in order to prevent influencing neighboring specimens. The cycling was terminated after 120 cycles. Results are presented in Table 4 with photographs in Figure 3.

RESULTS

The compressive strength of the mortars ranged between 3.4 and 6.3 MPa at 28 days and 3.15 and 7.5 MPa at 90 days. In general the masonry cement-lime mortars showed the greatest strength with the cement-lime putty showing the lowest.

The flexural bond strength values are for the most part much less than 0.3 MPa. Based on previous work (2) on bond strength using Nepean sandstone, the bond strength was considerably less. This supports the suggestion that individual stone properties can have a significant influence on the bond.

The flexural bond strength of the prisms with horizontal mortar joints is higher than those with vertical joints, with one exception. This suggests that packing the mortar in successive layers may not be as effective as laying the mortar horizontally, and having a load on it during curing. In addition, despite the effort to have a wooden jig against which the mason could apply pressure some flexibility may have contributed to the poor development of bond. The curing conditions may have had a secondary effect (the prisms with vertical joints were cured within the wooden molds used during construction).

The variation between mortar mixes and between 28 and 90 days is too variable to make any conclusions. Because of the high coefficient of variation, many more replicates need to be tested to be able to make comparisons.

The masonry cement-Type N hydrated lime mortar mix show the better freeze-thaw performance, completing all 120 cycles although some damage was present. The capstone full mortar specimen showed the best performance with the percent expansion less than a value of 0.04% which is considered as a failure criteria for mortar in severe environments (2). The plinth stone specimens showed earlier, but not severe failure with the cause of joint expansion due to mortar deterioration. (Fig. 3b). The foam backer rod/sealant specimens failed due to what appeared to be water at the back of the specimen. The damage at the back often exceeded that at the front. The manifestation of failure was the protrusion of the sealant from the specimen (Fig. 3c).

The cement- lime putty and cement-type S hydrated lime mixes did not perform as well. All the capstone joints reached 120 cycles, but with significant damage. The full mortar joints failed through progressive delamination of the mortar from the front to the back, as well as showing bond failure (Fig. 3d). The foam backer rod/sealant specimens failed relatively early, with significant damage to the back of specimen as well as the front.

It appears that the foam backer rod/sealant system did not provide any significant protection to the mortar below the sealant. This is probably due to the penetration of water down the back of the specimen and along the edges. This appears to point out a potential weakness of the configuration. If water passes the barrier it can pond and not be able to drain out.

This general poor performance of all the mortar mixes with Ohio stone was somewhat of a surprise. The mixes were based on previous tests which had shown good bond strength and freeze-thaw durability when combined with Nepean sandstone. Although not new, it does reinforce the observation that the performance of mortar is a function of its interaction with the stone in addition to the nature of the mortar.

CONCLUDING REMARKS

This investigation, as a first approach, provided information on the performance of masonry in horizontal projections:

- freeze-thaw durability of vertical joints is a function of the mortar performance, bond durability and water ingress to the back of the specimen. Vertical joints appear to have inherently weaker bond than horizontal joints. This necessitates the need for careful choice of mix design and attention to workmanship.

- there is no advantage to the use of a foam backer rod and sealant in vertical joints with Ohio sandstone. Where water can get behind the sealant, the deterioration progresses rapidly from the back to the front. This type of damage would not be noticed until complete failure occurs.

- the much lower bond strength achieved with Ohio stone in comparison with earlier tests with Nepean stone indicates the need for a good understanding of the bond capacity of a particular stone type.

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REFERENCES

1) Thomson, M.L., Suter, G.T. and L. Fontaine (1995). Freeze-thaw durability of mortars in historic masonry. Test Methodologies. In: Proceedings of the Seventh Canadian Masonry Symposium, McMaster University, Hamilton, Ontario, June pp. 700-711.

2) Synthesis Report to Parliamentary Precint Dedicated Unit on Mortar Research Program, August 1995. Public Works and Government Services Canada, Real Property Services for Canadian Heritage/Parks Canada, Heritage Conservation Program.

3) Thomson, M.L., Suter, G.T. and L. Fontaine (in press). Frost Durability Testing of Mortars for Conservation of Historic Nepean Sandstone Structures: Canadian Parliament Buildings. Bulletin of the Association for Preservation Technology.

4) Suter, G.T., Thomson, M.L. and L. Fontaine. (in press). Mortar Laboratory Study of Mechanical Properties for Repointing of Historic Stone Masonry. Bulletin of the Association for Preservation Technology.

5) ASTM standard C1072-94. Standard Method for Measurement of Masonry Flexural Bond Strength. American Society for Testing and Materials, Philadelphia, Pa.

6) Dutch standard NEN 2872. Testing of Stony Building Materials - Determination of Frost Resistance of Stony Building Materials. Single sided freezing in fresh water environment. Netherlands Standards Institute, Delft. 1989. 9 p.

Table 1 Mortar mixes

Mix #	Mix components	Volume proportions	Water/ binder ratio	Air (%)	Flow (%)	Vicat cone (mm)	Comp. Str. 28 day (MPa) (cov (%))	Comp. Str. 90 day (MPa) (cov (%))
6A	Mcw+Bd:Ln: Ss+Bc	1½+$^1/_{10}$:½:5+1¼	1.07	13.1	77	24	4.5 (1)	7.5 (11)
6B			1.07	13.9	82	23	4.5 (2)	6.3 (20)
6C			1.06	15.3	70	22	6.3 (12)	7.7 (18)
16A	PCw:LPn:Ss +AEA	1:2:7.5	0.81	7.0	42	6	3.4 (3)	5.4 (8)
16B			0.79	8.2	40	7	5.4 (2)	3.2 (8)
16C			0.87	9.9	66	13	3.6 (4)	3.7 (32)
22A	PCw:Ls:Ss	1:3:9	0.88	9.5	68	6	6.3 (7)	6.0 (12)

Binders		Aggregates	
PCw	White Portland Cement	Ss	Spratt sand custom sieved
MCw	White Masonry Cement	Bc	crushed brick custom sieved
Bd	Brick Dust < 75 µm	AEA	air entraining agent. Darex, WR Grace
Ln	Type N lime (Beachville High Calcium Lime, Beachville, Ontario)		
Ls	Type S lime (Mortaseal, Genlime, Ohio).		
LPn	lime putty from calcitic quicklime		

Table 2 Flexural Bond Strength

Mortar batch	Joint orientation	Flexural bond strength (MPa) (c.o.v. in brackets)	
		28 day	90 day
6A	horizontal	0.34 (27)	0.16 (81)
	vertical	0.095 (100)	<0.03
16A	horizontal	0.22 (75)	0.056 (87)
	vertical	0.12 (70)	0.13 (51)
22A	horizontal	0.072 (75)	0.22 (32)
	vertical	<0.03	0.15 (72)
c.o.v. = coefficient of variation (%)			

Table 3 Damage Rating Index

Damage Rating	Observed Damage
0	no apparent damage
1	minor surface crack
2	minor surface swelling
3	joint debonding/surface pop-off
4	significant surface spalling
5	significant mass loss

Table 4 Joint expansion data and damage index of freeze-thaw specimens

Specimen Number	Joint Design	Cycles completed	Maximum expansion (%)	Damage index (front)	Damage index (back)
6A-5°	full mortar joint	120	0.47	0	2
6B-20°	full mortar joint	120	0.08	0	0
6A-45°	full mortar joint	120	1.24	0	3
6B/C-5°	foam backer rod/sealant	120	0.14	0	3
6B/C-20°	foam backer rod/sealant	120	14.9	3	5
6B/C-45°	foam backer rod/sealant	120	5.64	3	3
16B-5°	full mortar joint	55	14.5	5	5
16B-20°	full mortar joint	75	17.2	5	5
16B-45°	full mortar joint	120	8.30	5	3
16A/C-5°	foam backer rod/sealant	75	11.8	4	3
16A/C-20°	foam backer rod/sealant	35	7.38	5	5
16A/C-45°	foam backer rod/sealant	120	14.3	4	2
22A-5°	full mortar joint	95	13.8	5	5
22A-20°	full mortar joint	35	11.2	5	5
22A-45°	full mortar joint	120	14.4	5	5

A to C signify different mortar batches for a particular mix.

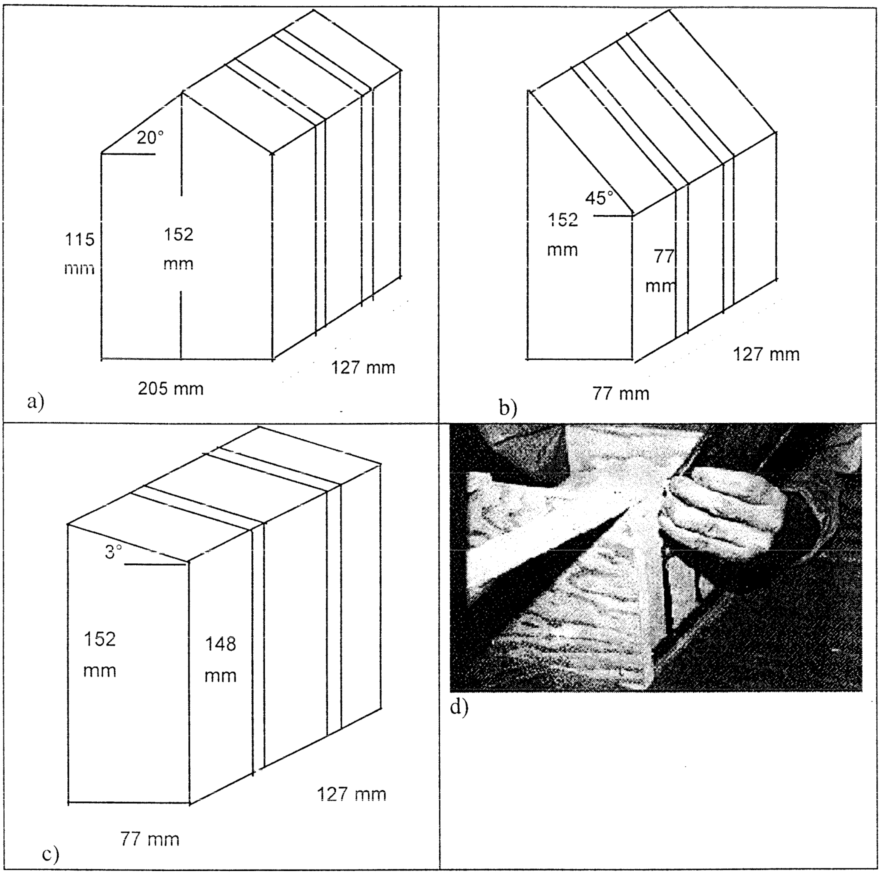

Figure 1. Configuration of stone specimens.
a) capstone, b) plinth stone, c) window sill, d) building a capstone prism.

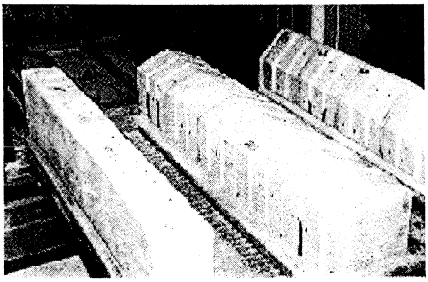

Figure 2 Ohio sandstone masonry prisms in the unidirectional freeze-thaw cabinet. Black markings are areas where the sealant is exposed. Plinth stones are on the right, capstones in the center, and window sill stones on the left.

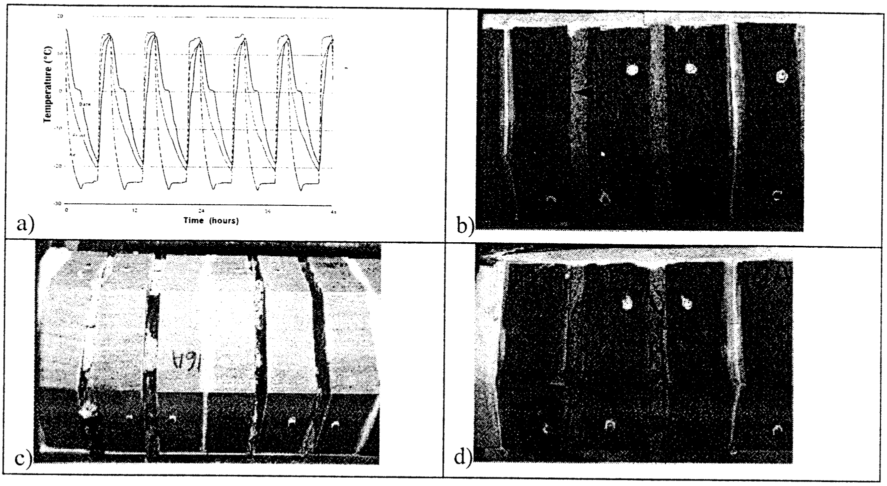

Figure 3

a) Temperature profiles within the unidirectional freeze-thaw cabinet. Profiles determined by placement of thermocouples in the air, at the front and back of specimens.

b) Mix 6A-45° showing good mortar performance. Bond failure of a joint resulted in large joint expansion.

c) Mix 16A/C-20° to left showing protrusion of sealant and Mix 16B-45° to the right showing complete deterioration of mortar.

d) Mix 22A-45° showing surface delamination of the mortar joint.

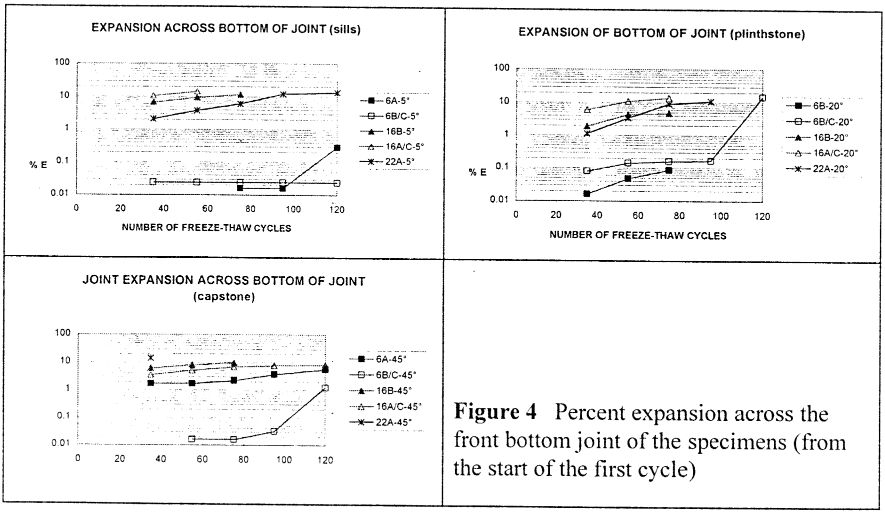

Figure 4 Percent expansion across the front bottom joint of the specimens (from the start of the first cycle)