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Frost damage to clay brick in a loadbearing masonry building

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Frost damage in the exterior, loadbearing, clay brick walls of two 5-storey apartment buildings could have seriously affected their loadbearing capacity if left unchecked. A coating applied to the exterior had not stopped further damage from occurring. This paper describes the work to determine the cause of the damage. The work included a condition survey, tests on the brick, and monitoring temperature and moisture levels in a section of the wall. Bricks on an easterly exposure suffered the most damage. The cause was traced to poor quality bricks combined with water infiltration mainly from rain. Remedial measures included cladding the exterior of the brickwork with an insulated siding and replacing severely damaged bricks.

Key words: building, masonry, loadbearing, frost resistance, clay brick, moisture, exterior insulation.

Les dommages causés par le gel aux murs de briques d'argile de deux immeubles de cinq étages auraient pu compromettre sérieusement leur portance si aucune attention ne leur avait été accordée. Un enduit appliqué sur la surface extérieure n'a pas empêché d'autres dommages de se produire. Cet article décrit les travaux effectués en vue de déterminer la cause des dommages. Ces travaux comprenaient une évaluation de l'état des murs, des essais de brique et un monitorage des niveaux de température et d'humidité dans une section de mur. Les briques exposées au vent de l'est ont subi le plus de dommages. La cause de ces dommages a été attribuée à la mauvaise qualité des briques et à une infiltration de l'eau de pluie. Les mesures correctrices incluaient le remplacement des briques très endommagées et le recouvrement de la façade extérieure de la maçonnerie de briques à l'aide d'un bardage isolé.

Mots clés : bâtiment, maçonnerie, portance, résistance au gel, brique d'argile, humidité, isolant extérieur.

[Traduit par la rédaction]

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Introduction

Frost damage to exterior clay bricks posed a potential problem to the loadbearing capacity of the exterior walls and balcony piers of two 5-storey apartment buildings in Ottawa constructed in 1973–1974. Structurally, the buildings consist of 175 mm in-situ reinforced concrete floors bearing onto 140 and 190 mm thick loadbearing masonry walls. The interior walls are concrete blockwork and the exterior walls are TTW (through-the-wall) clay brickwork (Fig. 1). TTW brick was used in Ontario for both loadbearing and non-loadbearing walls in low and moderate rise buildings especially over the period 1965–1976. A brief description of its development is given by Ritchie (1973). For exterior use, TTW walls were usually parged with a cement mortar on the inside to improve resistance to rain penetration. Rigid insulation board was stuck to the parging to improve thermal resistance. This was then covered with gypsum wall board (plaster has also been used). Finally, paint was applied to form the interior surface.

The exterior walls on the buildings under investigation have 12 mm thick parging, 36 mm expanded polystyrene insulation, and 12 mm drywall (Fig. 2). The brickwork contains nominal seismic reinforcement both vertically and horizontally. The floors bear a minimum of 100 mm onto the brickwork; a 50 mm brick facing covers the slab edges for a continuous masonry appearance of the exterior.

Significant spalling of the TTW brick due to frost action was noted in 1980. Several actions were taken to solve this problem. The roof parapet was redesigned to stop suspected ingress of water from the parapet into the brickwork, damaged bricks were replaced, and the exterior was painted with a *breathable* coating to stop penetration by rainwater. In spite of these repair measures, spalling of the brickwork continued, especially at repaired areas. This led to a more extensive investigation in 1987 (Suter and Maurenbrecher 1989). Other problems were also noted: (a) cracking of the concrete blockwork walls in the stairwells and (b) water penetration into a few apartments.

Condition survey

The extent of brickwork surface damage was documented and a number of wall sections were opened up to determine wall construction details and the extent of distress within the wall.

Detailed spalling maps were produced for each of the elevations (Fig. 3). Figure 4 illustrates such a map for a badly distressed region of elevation 15. The map is based on visual observation with the help of binoculars. The coating painted onto the wall can stretch considerably before tearing, therefore the onset of brick spalling can remain hidden for some time. This means that the amount of spalling is likely to have exceeded that recorded visually. Figure 5 shows photographs of the distressed region shown in Fig. 4. The damage there is typical of other badly deteriorated areas (about 5% of the total wall area).

NOTE: Written discussion of this paper is welcomed and will be received by the Editor until August 31, 1993 (address inside front cover).

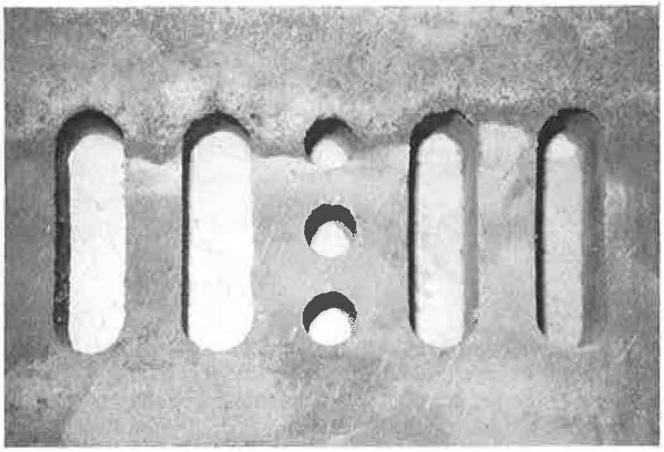

FIG. 1. TTW brick.

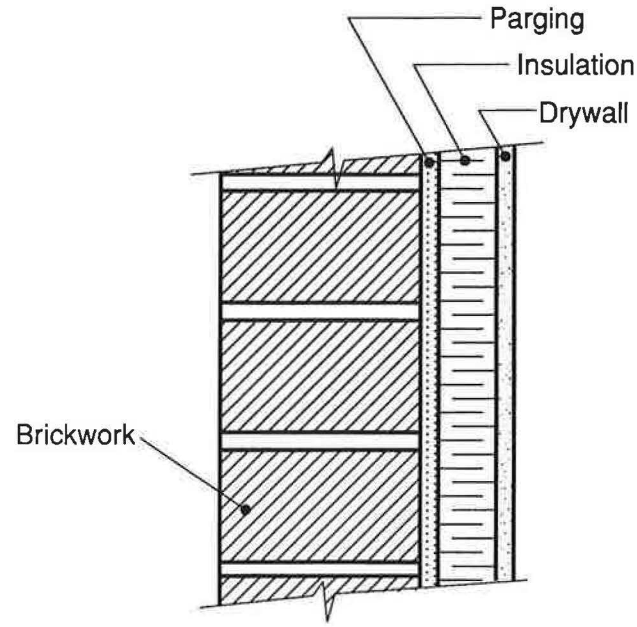

FIG. 2. Wall cross section.

The field survey identified the following key conditions:
- All elevations displayed some spalling distress. This included exterior brick piers supporting balconies.
- The most serious spalling occurred at NE elevations.
- The frequency of spalling increased near openings such as windows and at corners.

Because of serious deterioration in two of the walls facing NE, limited emergency repair measures were instituted to ensure the safety of these loadbearing walls. While carrying out these repairs and inspecting the wall at a number of inspection openings, the following wall conditions were identified in regions of badly deteriorated masonry:
- Masonry was found to hold moisture throughout its thickness.
- Even back faces of bricks were extensively spalled.
- Parging was extensively cracked and no longer adhered to the masonry.
- At previously repaired areas the mortar joints were only partially filled and damaged parging had not been repaired.

At inspection openings where no masonry distress was evident, parging was found to be continuous with few cracks.

Brick tests

A number of undamaged bricks were removed from the building to assess their freeze–thaw resistance using standard durability tests (CSA 1965, 1987).

The most relevant requirement in these standards, apart from an actual freeze–thaw test, is the saturation coefficient, the ratio of the amount of water absorbed after immersion for 24 hours in cold water to that absorbed after immersion for 5 hours in boiling water. It can be viewed as an indication of the space available in the brick to accommodate the movement of water when freezing occurs (the actual behaviour is more complex). The lower the saturation coefficient the more space is available for relief of pressures due to freezing, thus decreasing the likelihood of damage to the bricks. The latest edition of the CSA standard has introduced stricter requirements in order to reduce the number of durability performance failures. Most bricks now must have a coefficient of 0.78 or less compared to the previous value of 0.88. A sample of three bricks from the building had a mean coefficient of 0.85. Thus they complied with the earlier edition of the CSA standard but not the current one. More sophisticated tests such as determining the pore size distribution can help assess the durability of a brick. Such tests did confirm the poor durability of the present brick (Suter and Maurenbrecher 1989).

A brick not complying with the basic requirements may nevertheless still be used if it passes the 50 cycle freeze–thaw test in the standard. This test was not done, since it takes 3 months and it is not a good indicator of freeze–thaw durability in severe weather conditions (Marusin 1990). Newer test procedures are being developed which subject the bricks to conditions similar to that in practice — freezing from one side at different moisture contents. This approach and the CSA test are described by Arnott and Maurenbrecher (1990). Stupart (1989) gives a good overview of test methods and factors affecting the frost resistance of bricks.

Field monitoring

To help gain an understanding of how the exterior wall performs under cold weather conditions and in particular to assess the moisture distribution within the wall, temperature and moisture sensors were installed on the exterior and interior faces of two exterior walls in a corner apartment (NE corner). The walls were continuously monitored for a period of 9 months (Maurenbrecher and Suter 1989).

The results show both the inside and the outside of the brickwork were subject to freeze–thaw cycles. All monitored locations of the wall had moisture, the highest levels occurring in a recently repaired section. Damage occurred at this section during the measurement period. The thermal resistance of the wall was estimated to be less than 1.1 $m^2 \cdot {}^\circ C/W$, well below the present recommended value of 3.45 $m^2 \cdot {}^\circ C/W$ (ACNBC 1983). There are no mandatory minimum thermal requirements in Ontario except for single-family housing.

Assessment of problems

Satisfactory performance of an exterior wall assembly is judged very much by how well it carries out its functions to control air leakage, water penetration, and heat flow.

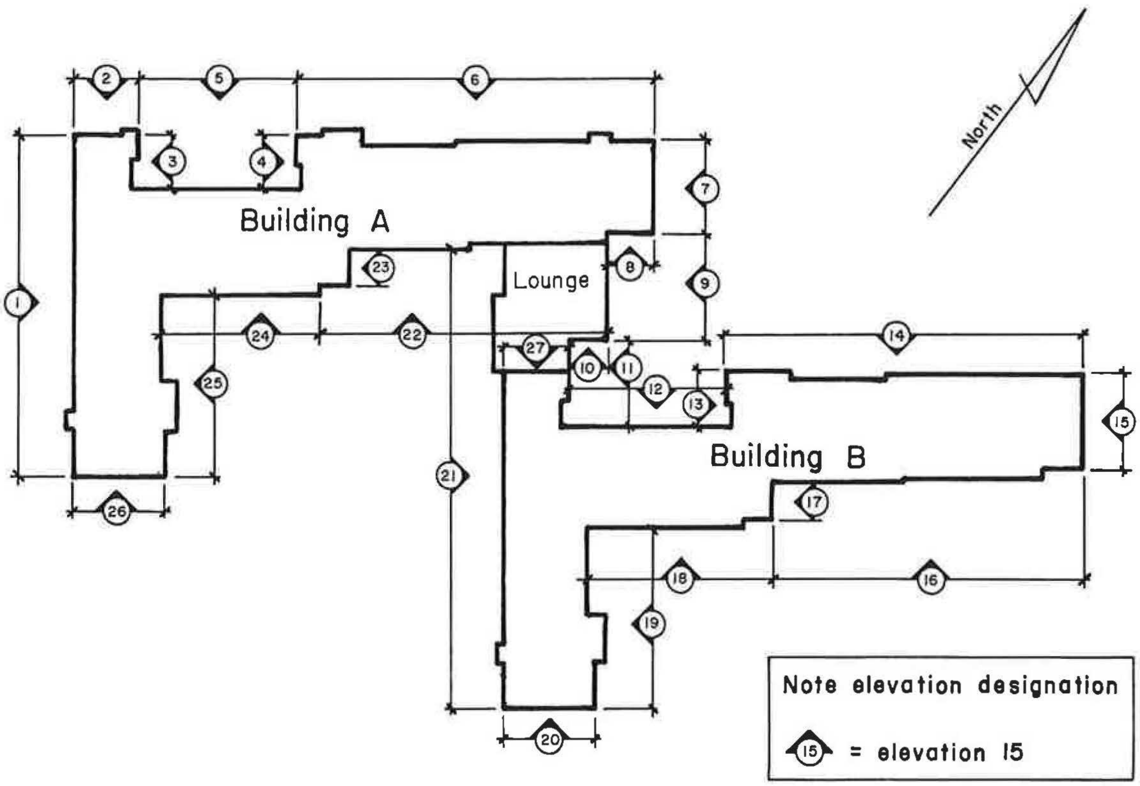

FIG. 3. Plan of buildings showing location of damage maps.

These factors are discussed by Hutcheon and Handegord (1983) and Brand (1990). An assessment of problems is discussed below under (*i*) as-designed conditions, (*ii*) as-built conditions, and (*iii*) deteriorated conditions.

As-designed conditions

1. Masonry will absorb moisture especially during driving rains. While this moisture largely evaporates, depending on factors such as wall orientation and wind conditions, the presence of a lower thermal gradient stemming from the attachment of insulation to the masonry's interior face will reduce the drying action.

2. Parging can be expected to control water leakage except under rare combinations of wind and prolonged periods of rain (Ritchie 1972). Nevertheless, the parging itself could become quite damp. This seems to be confirmed by experience, since the only observed leakage that occurred through the wall was at a repaired location with no parging. Though not a vapour barrier, parged masonry walls can be an effective air barrier if continuous and uncracked.

3. The expanded polystyrene insulation (beadboard) can transmit significant amounts of air and moisture and hence cannot be considered as a vapour barrier nor an air barrier (NRC 1989). The insulation can also absorb significant amounts of moisture but it is not hygroscopic.

4. Drywall with an appropriate coating of paint can act as a vapour barrier. It can also function as an air barrier if properly sealed at electrical outlets, openings, and intersections. However, paints, even of the same type, can have a large range of vapour permeabilities; most latex paints have a high vapour permeability. Canadian General Standards Board (CGSB 1989) gives methods for determining vapour permeance. In this building, the electrical outlets were not sealed. The paint on the walls was not analysed.

5. Moist indoor air exfiltrating through or circulating in the wall can deposit its moisture as condensate on cold surfaces or in cold materials. Dewpoint calculations indicate that under typical Ottawa cold weather conditions of $-10°C$ to $+5°C$ and interior relative humidities of 20% to 50%, moisture vapour in exfiltrating air could condense within the masonry walls.

6. Differential movement between the interior concrete block walls and the exterior clay brick walls was the cause of stepped cracks observed in the exposed face of block cross-walls in all the stairwells. The largest cracks, up to 1 mm, occurred in the top storey. The concrete block walls have greater drying shrinkage, a lower elastic modulus, and greater creep than the clay brick walls. Furthermore, clay bricks undergo long-term expansion due to absorption of moisture from the atmosphere. Superimposed on these long-term movements are smaller short-term cyclic movements caused by temperature differences between the outside and the inside.

7. Water leakage has been reported in only a few apartments. The most recent case of water leakage, investigated by the second author, showed that the water entered through a corner gap in the track of the horizontal slider in the window. Damp drywall in another apartment was caused by water ingress at a section of a wall with severe frost damage.

As-built conditions

Two factors of the as-built wall assembly had a major influence on the brickwork deterioration. The first factor was the particular brick used; and the second, wall imperfections.

The brick was clearly shown to be nondurable in service and in laboratory tests. The quality of the brick may vary,

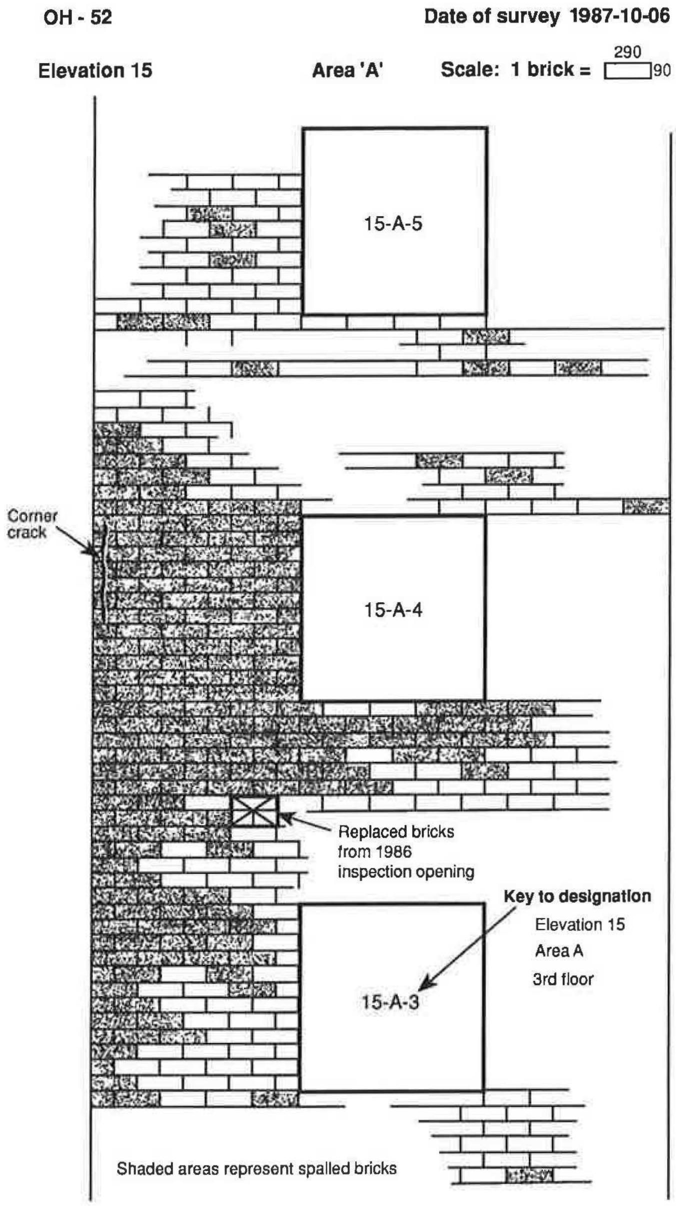

FIG. 4. Damage map for part of elevation 15.

and that in turn causes variable performance in service. Varying environmental conditions in service also affect durability. Of special interest under cold weather conditions are the effect of wall orientation on moisture, temperature variations, freeze–thaw action, and wind. For Ottawa conditions, the following points are relevant:

1. Much higher winter temperatures on a south-facing wall mean that such walls have a much better chance to dry out than a north- or east-facing wall. On the other hand, should a south-facing wall not have a chance to dry out (for example, a constant supply of moisture from melting snow), the higher number of freeze–thaw cycles will cause greater damage (thawing in the sun during the day, freezing at night). The first sign of damage to a section which had been recently repaired was at the southeast face at its junction with the northeast face.

2. Wind has an important effect on air leakage in and out of buildings and on rain wetting of walls. Rain wetting in Ottawa is most intense for walls facing E and ENE (Robinson and Baker 1975). Tests in Ottawa also showed that, during the winter months, bricks facing east and north had a high moisture content while those facing south and west had a low one (Ritchie and Davison 1968; Crocker 1970). These factors explain why most damage occurred on the NE elevations of the walls. Figure 6 shows a typical wetting pattern on a NE elevation. The monitoring also indicated that rain had the largest effect on the moisture levels in the wall. This is confirmed by the badly damaged balcony piers which could only have received their moisture from an external source such as rain. Prevailing winter winds from a WNW direction cause net outward air pressures on the ESE exposure. In upper floors, these outward pressures can combine with those of stack effect to produce exfiltration of moist air. However, the building was not pressurized (the apartments use electric baseboard heating). The monitored area of the wall did not show any noticeable contribution from exfiltration except at a damaged corner of the wall where local delamination had occurred and the interior drywall was damaged. There, air exfiltration temporarily increased the moisture on the inside surface of the brickwork on calm days or with winds from a westerly direction.

3. Imperfections in the wall assembly can also influence the performance of exterior walls. Openings around windows and at electric baseboard heaters increase the chance of air exfiltration. Gaps between the insulation boards reduce the thermal resistance of the wall. The boards had approximately 3 mm gaps between them, although some gaps of 6–10 mm were observed between them and the ceiling slab. Chases for electrical conduits were also cut into the insulation. The insulation boards were stuck onto the parging with adhesive dabs, which meant it was possible for air to circulate from behind the insulation to the gaps between the boards through to any spaces between the insulation and the drywall (glued to the insulation). This *short circuits* the insulation.

Deteriorated conditions

The deteriorated conditions can be significantly influenced by

- the presence of a coating,
- the degree of masonry distress,
- parging discontinuities (cracked parging and parging that was not replaced in repaired areas),
- unfilled mortar joints from previous repairs,
- drywall imperfections due to periodic wetting,
- caulking deterioration.

Of these factors, the first two are believed to be the most influential ones. The presence of a coating can be both beneficial and detrimental. It helps keep out moisture from wind-driven rain and provides a uniform appearance to the wall, since bricks replaced during repairs were not the same as the original bricks. On the other hand, the coating only has a limited breathing ability and therefore can only vent a limited amount of moisture from within the brickwork. The coating will not cope if a significant quantity of water enters the wall. This could occur at locations where the coating was disrupted, at openings around windows, and where any air exfiltration deposited water within the wall. The coating can therefore allow much larger amounts of moisture to build up within the brick and hold it there for longer periods. The rate of frost damage depends greatly on the amount of moisture in the brick when it freezes.

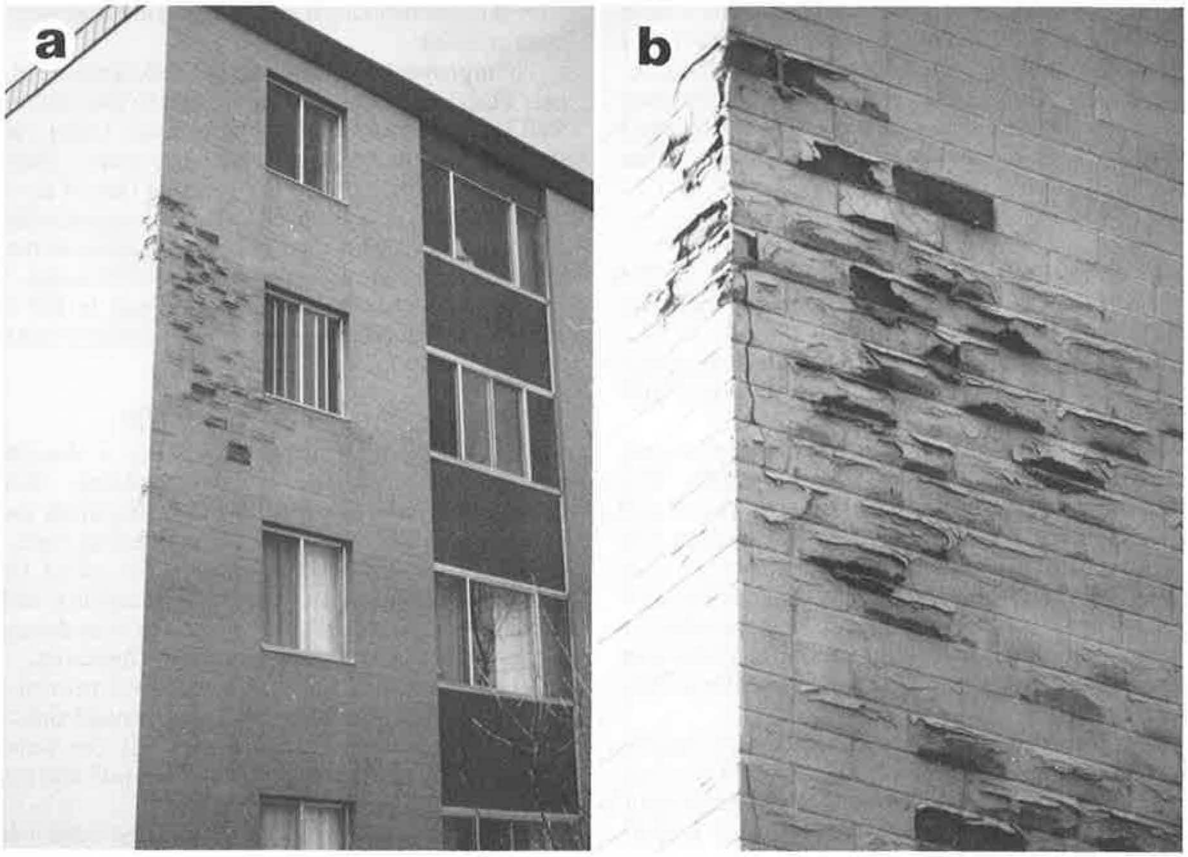

FIG. 5. (*a*) Partial view of elevation 15 and (*b*) close-up of damage.

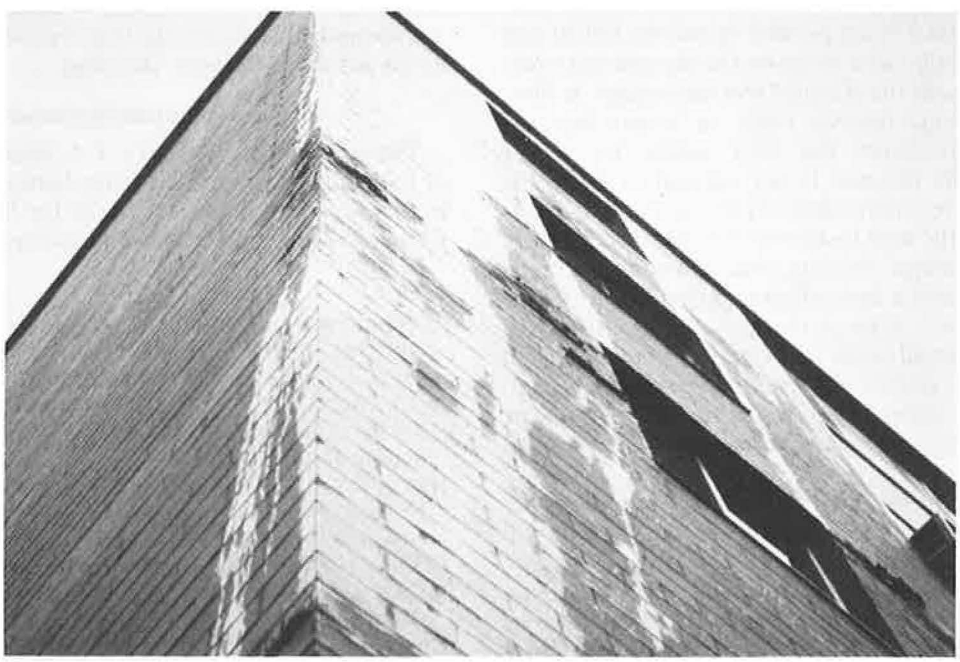

FIG. 6. Wetting pattern on elevation 15 (NE exposure).

Extruded bricks with a moisture content of 75–80% of the total pore volume or higher are more susceptible to frost damage (NRC 1984). Any freeze–thaw damage, which disrupts the coating, will allow increased moisture uptake and accelerate the spalling.

This explains why, in the first 2–3 years after the coating was applied, spalling distress progressed slowly but then advanced at an increasing rate. This points to the need for prompt repairs to limit the extent of damage and greatly reduce the eventual repair costs.

Previous repairs had been performed from the exterior, which meant the repaired area could not have been parged on the inside nor would the mortar joints have been properly filled. The repairs were also carried out in the latter part of the year and therefore the external coating may have been applied before the area had a chance to dry out. This would have increased the chance of frost damage occurring again. Failure of only part of the exterior would have allowed easy entry of rainwater (no parging on the interior of the repaired area), leading to increased moisture in the wall and further frost damage.

Remedial work

In arriving at an appropriate remedial scheme for the buildings' problems, the following key components underlying a repair philosophy were considered:

1. Since the TTW walls are loadbearing, walls with severe frost damage must be repaired to achieve sound structural conditions.
2. High moisture levels in the brick walls must be reduced to avoid freeze–thaw deterioration of the bricks. The investigation indicated that rain is the main source of this moisture; secondary sources are due to air exfiltration and direct moisture paths at windows. Moisture from rain can be controlled by adding a new exterior cladding; exfiltration and flow of inside air within the wall can be controlled by improvements in the internal air and vapour barriers; and direct moisture paths at windows can be controlled by sealing and re-caulking.
3. Added exterior insulation further reduces the chance of the frost damage to the bricks. Steady-state thermal calculations show that 50 mm of insulation on the exterior will ensure the masonry stays above freezing at air temperatures down to $-25°C$ (the January 2.5% design temperature for Ottawa). For Ottawa conditions this means the brick would rarely be subjected to freezing action except near window returns where it is not possible to add the full 50 mm of insulation. Insulation also increases the thermal resistance of the wall and reduces the effect of thermal bridges at floor levels and intersecting interior walls. A 50 mm layer of insulation will increase the RSI value by about $1.7\ m^2 \cdot °C/W$. This increase is not enough to bring the wall up to current recommended requirements, but nevertheless will reduce the heat losses through the wall by more than half. The remedial cladding chosen was an insulated proprietary system with a stucco finish applied to the exterior of the walls ($5100\ m^2$). Prior to the application of this cladding, severely damaged areas of brick were replaced with standard clay brick, since TTW bricks were no longer available. The repaired areas were parged on the inside. The bricks in the balcony piers were replaced with autoclaved concrete block.

The existing coating on the wall was not removed, as the added extruded polystyrene insulation on the exterior will in any case inhibit drying to the exterior. Localized high moisture levels within the wall are expected to dissipate towards the drier adjacent masonry inside the walls and, over the long term, to the exterior. If the interior face of the wall has a lower resistance to vapour diffusion than the outside face, there could be an increase in moisture level with time. Another possible source of moisture could be rain if the exterior seals fail; water may enter the system by gravity. It is therefore important that the exterior cladding is maintained. It would be worthwhile to monitor the moisture content of such a wall system over a period of several years in the colder Canadian climate. Experience in northern Europe with exterior insulation systems on solid masonry walls has been positive.

To improve the air and vapour resistance of the interior part of the wall, sealant was applied to the junctions of the wall board with the floors and ceilings. Other openings in the wall such as wall plugs were also sealed. Two coats of alkyd paint were applied to the inside face of the walls. All windows were also replaced to further upgrade the building envelope. Acrylic latex caulking was applied at the junction between the window frames and the wall board. The total cost, excluding the new windows, was in the region of \$2 000 000. The replacement of the windows costs an additional \$300 000.

Concluding remarks

Clay brickwork normally provides a durable, maintenance-free cladding. In this building, freeze–thaw deterioration of poor quality bricks impaired the serviceability and safety of some of the loadbearing walls. The new edition of the clay brick standard (CSA A82.1 1987), with stricter requirements for freeze–thaw durability, will improve the situation by reducing the chance of frost damage to clay bricks being incorporated in today's buildings.

A new, insulated cladding system was provided to keep out moisture from the exterior and protect the brickwork from most freezing temperatures. At the same time it improved the thermal resistance of the wall and reduced the effect of cold bridges.

It would be worthwhile monitoring the behaviour of such systems in the Canadian climate. For the present building, it would help assess what will happen to existing moisture in the brickwork, the possibility of moisture buildup because of vapour diffusion, and the long-term behaviour of the seals in the insulated exterior cladding.

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ACNBC. 1983. Measures for energy conservation in new buildings. NRCC No. 22432, Associate Committee of the National Building Code, National Research Council of Canada, Ottawa, Ont.

Arnott, M.R., and Maurenbrecher, A.H.P. 1990. An alternative test for determining the frost resistance of bricks. The Masonry Society Journal, **9**(1): 105.

Brand, R.G. 1990. Architectural details for insulated buildings. Nelson Canada, Scarborough, Ont., and van Nostrand Reinhold, New York, N.Y.

CGSB. 1989. Method for permeance of coated wallboard. CAN/CGSB-1.501-M89, Canadian General Standards Board, Ottawa, Ont.

Crocker, C.R. 1970. Influence of orientation on exterior cladding. Canadian Building Digest No. 126, Division of Building Research, National Research Council of Canada, Ottawa, Ont.

CSA. 1965, 1987. Burned clay brick. CSA Standard A82.1, Canadian Standards Association, Rexdale, Ont.

Hutcheon, N.B., and Handegord, G.O.P. 1983 (reprinted 1989). Building science for a cold climate. Construction Technology Centre Atlantic Inc, P.O. Box 4400, Fredericton, N.B.

Marusin, S.L. 1990. Failure of brick with high compressive strength, low water absorption, and saturation coefficient higher than 0.80 under severe weather conditions. Ceramic Bulletin, **69**(8): 1332–1337.

Maurenbrecher, A.H.P., and Suter, G.T. 1989. A loadbearing clay brick masonry deterioration problem: monitoring temperature and moisture. Proceedings, 5th Canadian Masonry Symposium, Vol. 2, The University of British Columbia, Vancouver, B.C., pp. 771–779.

NRC. 1984. Frost durability of clay bricks — evaluation criteria and quality control. NRCC 23294, Proceedings No. 8, Division of Building Research, National Research Council of Canada, Ottawa, Ont.

NRC. 1989. An air barrier for the building envelope. Proceedings of Building Science Insight '86. Proceeding No. 13, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ont.

Ritchie, T. 1972. Water penetration tests of TTW brick walls. Building Research Note 86, Division of Building Research, National Research Council of Canada, Ottawa, Ont.

Ritchie, T. 1973. T.T.W. brick walls. Journal of Canadian Ceramic Society, **42**: 57–60.

Ritchie, T., and Davison, J.I. 1968. Moisture content and freeze-thaw cycles of masonry materials. Journal of Materials. **3**(3): 658–671.

Robinson, G., and Baker, M.C. 1975. Wind-driven rain and buildings. NRCC 14792, Technical Paper 445, Division of Building Research, National Research Council of Canada, Ottawa, Ont.

Stupart, A.W. 1989. A survey of literature relating to frost damage in bricks. Masonry International, **3**(2): 42–50.

Suter, G.T., and Maurenbrecher, A.H.P. 1989. A loadbearing clay brick masonry deterioration problem: case study. Proceedings, 5th Canadian Masonry Symposium, Vol. 2, The University of British Columbia, Vancouver, B.C., pp. 757–769.