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L'ACTION DE LA CONGELATION ET DE LA DECONGELATION SUR LA BRIQUE

SOMMAIRE

La durabilité d'une brique relativement à l'action de congélation et de décongélation dépend de deux facteurs: (1) les propriétés de la brique, et (2) les conditions d'utilisation. Le présent article traite surtout des conditions d'utilisation qui concernent l'action de congélation et de décongélation, en particulier les changements de température que subit une brique dans un mur et le montant d'humidité que contient les pores d'une brique lorsque celle-ci est congelée. Le mouvement des plans de congélation dans un mur, le nombre de cycles de congélation et de décongélation et leur dépendance de l'orientation du mur, ainsi que divers facteurs qui influencent le contenu en vapeur d'eau d'une brique, par exemple la situation géographique et l'orientation, sont étudiés relativement aux dommages que subissent les briques sous l'action de la congélation et de la décongélation.

Freeze-thaw action on brick

T. Ritchie

ABSTRACT. The durability of a brick with regard to freeze-thaw action depends on two factors: (1) the properties of the brick, and (2) the conditions under which it is used in service. This paper deals mainly with those service conditions that affect freeze-thaw action, particularly the temperature changes experienced by a brick in a wall and the amount of moisture in the pores of a brick when it is frozen. The movement of freezing planes through a wall, the number of freeze-thaw cycles and their dependence on the orientation of the wall, and various factors that affect a brick's moisture content such as geographical location and orientation are discussed in relation to freeze-thaw damage to bricks.

Brick walls have a long history of use and of generally satisfactory performance in Canada, a country which abounds with century-old, and older, brick buildings apparently unaffected by any form of weathering or decay in spite of the harshness of the winter weather. Occasionally, however, instances of brick decay do occur, frequently after only a few years of service, and often involving many bricks in a wall, resulting in great disfigurement of the building and heavy repair costs.

Brick decay is usually attributed to the effects of freezing and thawing. Even so, the identification of frost action as the agent of decay in a particular instance of failure is generally an assumption, because a brick may crumble or spall from salt crystallization, excessive structural stressing, or from a combination of factors. There appears to be no means other than the considered judgment of the observer to identify a particular case of brick decay as the result of freezing and thawing.

Factors in durability

The durability of a brick depends on two factors: its own physical characteristics, and the conditions under which it is used.

In connection with the first factor, the influence of such properties as strength and pore structure on the durability of bricks when alternately frozen and thawed has been studied in great detail. However, the test methods used have been arbitrarily established, mainly for convenience rather than on the basis of duplicating the process by which a brick is frozen in a wall. In the work of McBurney[1] and McBurney and Lovewell,[2] for example, the test bricks were soaked in water prior to freezing, partially immersed in water during their freezing, and thawed by soaking in water. Their method of test and the results obtained have provided the basis for the test methods and provisions of the current ASTM and CSA standards.[3,4] According to these standards, for a brick to be classed as durable, it must be able to withstand 50 freeze-thaw cycles determined by test or indirectly determined by the brick possessing certain combinations of values of compressive strength, water absorption and saturation coefficient. But the brick's durability so determined may differ greatly from its durability under "field" conditions.

As stated earlier, a brick's durability depends not only on its physical properties but also on its conditions of use. This second subject forms the main topic of this paper and involves such considerations as the influence of the brick's exposure and service conditions on the process of freezing, the number of freezings, and the moisture content of the brick when frozen. These factors are important to the performance of the brick and must be understood and accounted for in establishing a

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test method for brick durability which will provide a more realistic assessment of brick performance than that obtained from present methods.

The freezing of bricks in a wall

The temperature of a brick in the wall of a building depends on the air temperature outside and inside the building. In centrally heated buildings the range of inside air temperature is small, but in Canada the range of outside air temperature is large both in the daily and yearly cycles of change. A brick's temperature is also influenced by the sun's radiation, which has a strong effect on south-facing walls but none on north-facing walls.

On a cold, sunny, winter day when the outside air temperature rises only a few degrees above zero, the surface temperature of bricks in a south-facing wall rises well above 60°F while those in a north-facing wall are only slightly warmer than air temperature. This typical situation is illustrated in Figure 1, plotted from temperature records of the insulated walls of a test building in Ottawa constructed of "SCR" bricks by the Division of Building Research (DBR). These records show that on two successive days in February the surface temperature of the south-facing brick rose to 66°F, subsequently falling below zero, in contrast to the behaviour of the north-facing brick whose surface temperature was only slightly higher than that of the air and remained well below the freezing point of water.

Freezing and thawing

The temperature of a brick in a wall is rarely, if ever, uniform; the brick's outer surface responds to air temperature changes and to the sun's radiation before the remainder of the brick. Figure 2 shows outside and inside surface temperatures of the "SCR" brick of the south-facing wall of the test building in Ottawa. Although the outside surface temperature reached 32°F at about 10:30 a.m. as it rose to its peak of 66°F, it was not until three hours later that the inner surface had reached 32°F, with a peak temperature much less than that of the brick's outer surface. Similarly, in the cooling of the brick in the afternoon, the outside surface temperature reached 32°F shortly after 5:00 p.m., but the inside surface of the brick did not reach this temperature until four hours later.

The passage of freezing planes through a brick

Temperature records of the test building were maintained not only of the outside and inside brick surface temperatures but also of temperatures at several locations within the brick, thus permitting a plot to be made of the location with time of the freezing plane, i.e. where at a given time the temperature of the brick is 32°F. Such a plot is shown in Figure 3, which depicts the width of the brick against a time scale for the same two days as in Figures 1 and 2. The freezing and thawing of the brick may have resulted from the passages of a "freezing wave" across the brick, the time taken for its passage through the brick being approximately four hours.

Thermal stresses

The temperature difference between the outside and inside surfaces of a brick, which is apparent in Figure 2, must result in a thermal stressing of the brick. The temperature gradient changes with time (Figure 4), reaching a maximum value of 40°F for the days under

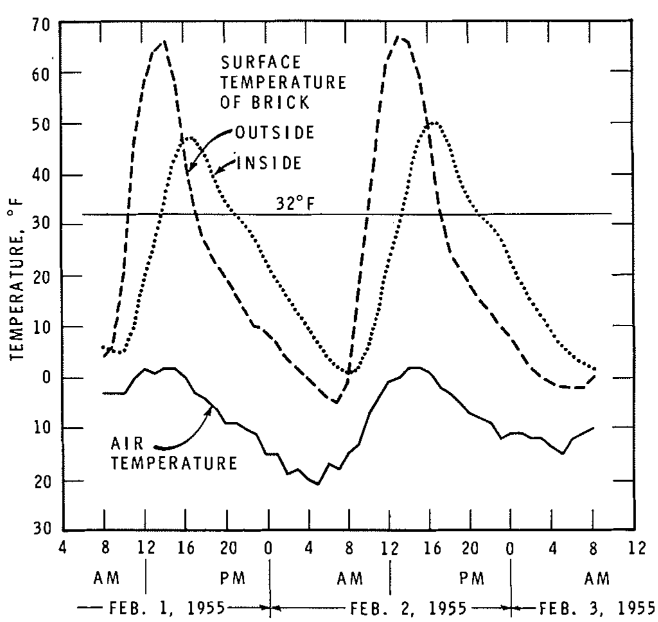

FIGURE 1. Air temperature and wall surface temperatures; insulated walls of a building in Ottawa of "SCR" bricks.

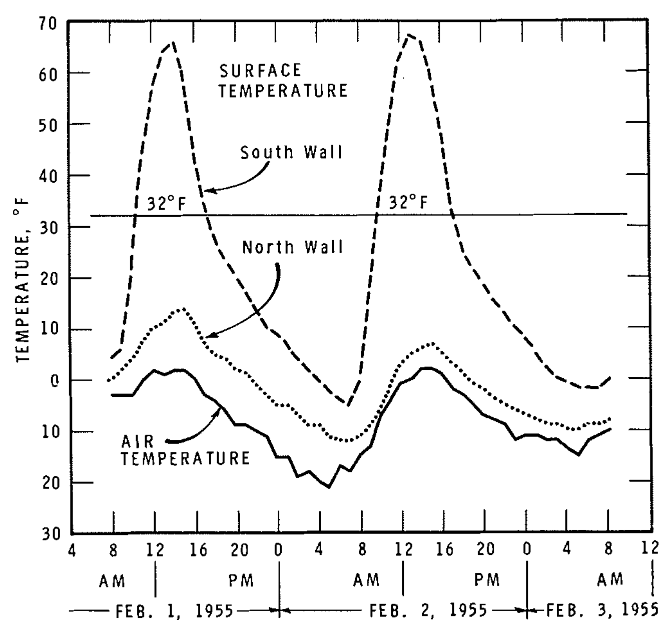

FIGURE 2. Surface temperatures, outside and inside, of an "SCR" brick of a south-facing insulated wall in Ottawa.

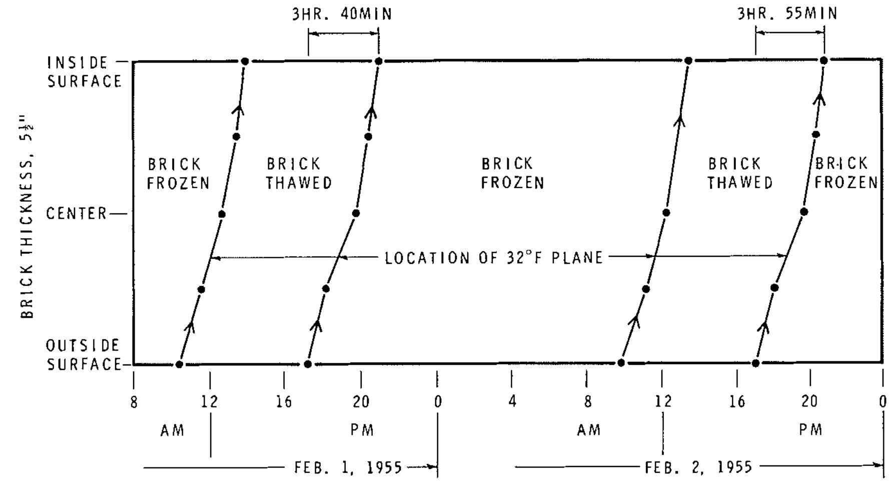

FIGURE 3. Movement of freezing plane (32°F) through an "SCR" brick wall.

consideration. Calculations to determine the compressive stress required to restrain the movement due to this maximum thermal gradient, using the assumed values of modulus of elasticity and of coefficient of thermal expansion indicated in Figure 4, show that only a stress of relatively small magnitude (a few hundred pounds per square inch in compression) is required to restrain the thermal expansion. Compared with the ultimate compressive strength of bricks, which is generally about 20 times this value, the stresses resulting from thermal gradients in a brick are small; their repetitive nature, however, may have an influence on the behaviour of the brick.

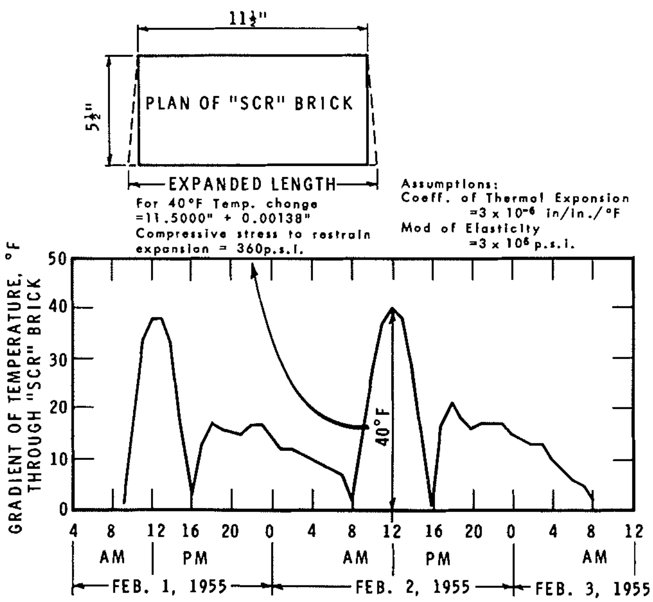

FIGURE 4. Temperature gradient across an "SCR" brick and potential thermal stressing.

Number of freeze-thaw cycles

The sun's radiation greatly influences the temperature changes of a brick, thus the orientation of a wall affects the number of freeze-thaw cycles experienced by a brick in service. Figure 1 shows that the south-facing brick on each of two successive days was thawed and frozen, while the north-facing brick remained frozen. In winter the relative number of freezings was 40, 72, 102 and 68 for bricks in the north, east, south and west walls, respectively, of the building.

Geographical location also has an influence. In a study comparing freeze-thaw cycles of bricks in Ottawa and Halifax,[5] bricks exposed at Halifax experienced more freezings than those in Ottawa (see table).

Effect of orientation and geographical location on the number of freeze-thaw cycles

Brick facing	Number of freeze-thaw cycles			
	OTTAWA		HALIFAX	
	1963–1964	1964–1965	1963–1964	1964–1965
N	47	65	65	81
E	51	70	66	83
S	81	98	86	108
W	63	79	87	88

Moisture content

A brick must contain water in its pores for it to be damaged by freezing. The amount of water in the brick, for a given condition of freezing, determines the extent of damage.[6] Although it is possible for walls to be wetted by the condensation of water vapour carried in air leaking outwards through cracks in the walls, under normal conditions the water in the pores of a brick in a wall is derived from rain.

When rain falls on a wall the wetting it causes is not uniform. Bricks near the top of the wall receive more wetting than those at lower levels. This difference

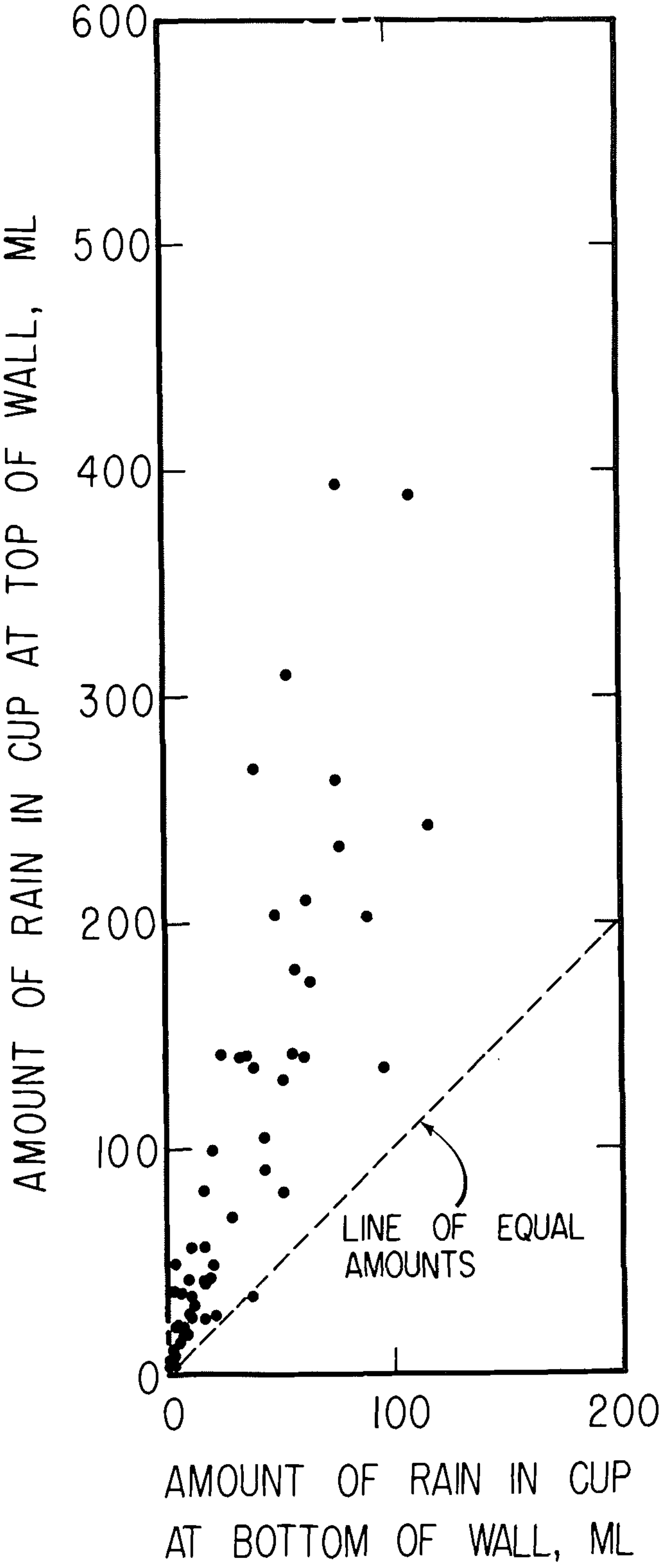

FIGURE 5. Difference in wetting of a wall at its top and bottom.

in the pattern of wetting was observed in a DBR study in which rain cups were attached to a wall, one near the top and another directly beneath it at a lower level. The cups were designed so that the amount of water caught during a rainstorm corresponded as closely as possible to the amount of water that would have struck the area of the wall covered by the cup.

Figure 5 shows some of the results obtained in this study. Each dot of the graph represents the corresponding amounts of water caught in the upper and lower cups in a single rainstorm. The cup at the upper level consistently received more rain than the lower cup, in some cases by a factor of four. The greater intensity of wetting at the top of a wall than at the bottom explains why decayed bricks are frequently seen near the top of the wall and not elsewhere, since frost damage of bricks is closely related to moisture content.

Rainfalls vary with geographical location. There is also a directional aspect to rainfall and to the wetting of walls, as shown by the results of a DBR study.[5] In this study similar samples of a relatively absorptive brick were exposed to each of the four directions, and in such a way that only the face of the brick could be wetted by rain. The moisture content of the four samples varied considerably, as shown in Figure 6, which compares the moisture content of bricks exposed in Ottawa. Bricks facing east and north remained at a relatively high moisture content during the winter but those facing west and south had little moisture in them throughout the winter. Similar bricks exposed in Halifax were higher in moisture content than those in Ottawa, and the directional effect was different: the bricks facing east and south were high in moisture throughout the winter while those facing west and north were much lower in moisture content.

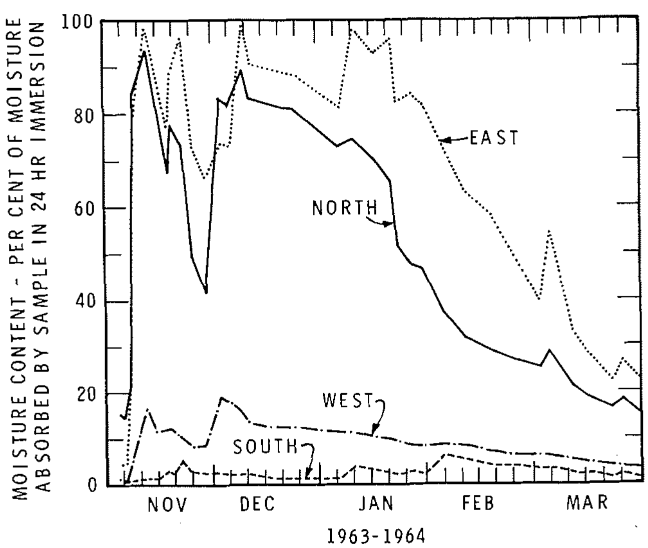

FIGURE 6. Directional effect on the moisture content of a brick exposed in Ottawa.

Redistribution of moisture in a brick on freezing

The water in the pores of a brick is not static during the freezing process, but is mobile to the extent that a significant redistribution of the water may take place during the freezing of the brick.

The extent of this redistribution has been determined in DBR experiments with many different bricks which were cut into bars one inch in cross-section and of length equal to the width of the brick. The bars, after being saturated with water, were subjected to unidirectional freezing along the long axis of the bar, to simulate the passage of a freezing plane through the brick in a wall. After the passage of the freezing plane, each bar was broken into four pieces which were weighed, dried and reweighed, to determine the moisture content.

The results of tests of 10 different bricks are presented in Figure 7. The dotted lines represent the average moisture content of each brick before it was frozen. The solid line joins the values of moisture content after freezing of the four parts into which the bar was broken. Except for two of the bricks, a significant redistribution of moisture took place: moisture content of the "outer" (first-frozen) part of the brick became considerably less than the original moisture content, while that of the "inner" (last-frozen) part was apparently greatly increased over the original moisture content. Since the brick was already saturated, however, the excess water was forced from it, forming an ice coating on the end surface of the bar after the passage of the freezing plane.

The two exceptions to increased moisture content of the "inside" part of the brick relate to bricks of low absorption, which had reduced moisture content both in the first- and last-frozen parts. The relatively small amount of water in these saturated bricks made difficult an accurate determination of the moisture content of the small parts into which the bars were broken.

Conclusions

The service conditions of a brick, which govern its wetting and freezing, and thus its durability, vary greatly depending on the geographical location of the particular building, local weather conditions, the orientation of the wall in which the brick serves, and its location in that wall.

The temperature changes of a brick in a wall depend not only on changes in the air temperature but also on the sun's radiation, thus there is a directional effect on the number of freeze-thaw cycles experienced by a brick. There is also a directional effect on the wetting of bricks by rain, as well as an effect from their location in the wall, those near its top being more heavily wetted by rain than those in the lower portion. Although water must be present in the pores of a brick for damage from freezing to take place, the water is not static but redistributes itself in the brick when a freezing plane passes through it.

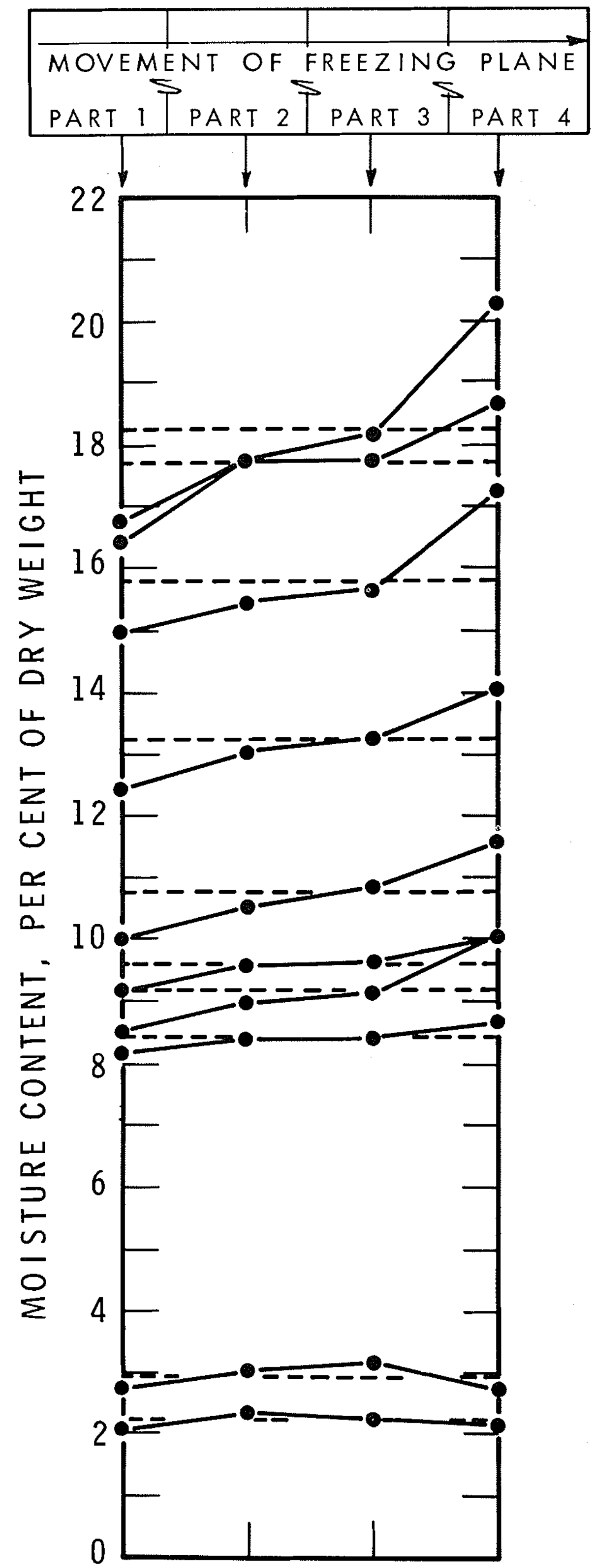

FIGURE 7. Moisture distribution in saturated bricks after unidirectional passage of a freezing plane.

The ideal test for brick durability with respect to frost action would be one which not only reproduces the conditions of the brick's service in a wall, but also accelerates their effects. This would provide a realistic assessment of durability within a reasonably short period of time. It would also minimize the costs of the tests and would allow test results to be applied before and during the construction of the building. Obviously the development of a test along these lines will be difficult to achieve because of the extreme variability of the conditions — wetness and freezing — that affect brick durability, but the goal is worth pursuing.

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References

1 J. W. McBurney. The weathering of structural clay products: a review. *Amer. Soc. Test. Mater., Proc.* Vol. 31, Part II, 1931.

2 J. W. McBurney and C. E. Lovewell. Strength, water absorption and weather resistance of building bricks produced in the United States. *Amer. Soc. Test. Mater., Proc.* Vol. 33, Part II, 1933.

3 Specifications for building brick, Designation C62; *Amer. Soc. Test. Mater.,* Philadelphia, U.S.A.

4 C.S.A. Standard A82.1-1965. Burned clay brick. *Can. Stand. Ass.,* Rexdale, Ontario.

5 T. Ritchie and J. I. Davison. Moisture content and freeze-thaw cycles of masonry materials. *Amer. Soc. Test. Mater., J. Mater.,* 3(3), September, 1968.

6 T. Ritchie. Factors affecting frost damage to clay bricks. *Nat. Res. Counc. Can., Div. Bldg. Res., Bldg. Res. Note No. 62,* Ottawa, 1968.