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CANADA

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Stability and Durability of Masonry Materials

Neil B. Hutcheon

DIMENSIONAL STABILITY AND DURABILITY are two major requirements common to all building materials. Since no materials are perfectly stable and durable even within the range of conditions provided by the weather, it becomes necessary to recognize the limitations and difficulties inherent in this situation.

The need for durability is, at first glance, rather more readily appreciated than the need for dimensional stability. A building material must maintain its properties within reasonable limits so that it will continue to serve its function in the building construction for the required length of time. Most building materials must be durable for the life of the structure, that is for fifty years or more. The evaluation of the durability of a material becomes a difficult task since it can finally only be proven by the passage of time.

It is no longer possible, in this age of rapid technological development, to wait fifty years or more for the evaluation of the durability of a proposed new building material. Ways have to be found of assessing materials in a few days or weeks in the laboratory by means of accelerated aging and weathering tests. Again, however, as with the materials themselves, these methods can only finally be proven by the passage of time.

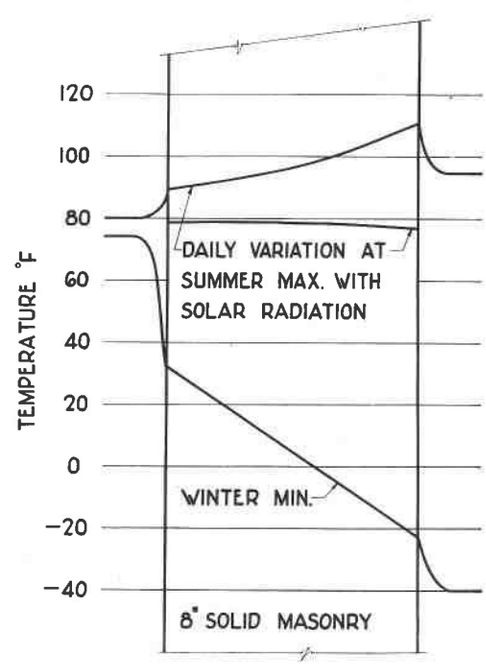
Dimensional stability and durability are not unrelated. A material which exhibits marked expansion and contraction with changes in temperature or moisture content may, under certain conditions of use, be capable of destroying itself through these mechanisms. Dimensional changes are of importance when they become large enough to create significant stresses within a material or a combination of materials or in a structure as a whole. The designer must continually be on the watch for the possibility of such "self loading" and must make appropriate allowances where these conditions cannot be avoided. It is safe to say that many of the refinements in the use of masonry materials which may be expected over the next few years will be in the direction of a greater realization of the dimensional changes which may take place in these materials, coupled with improved ways of dealing with them. In some cases it will be possible to modify a material to improve its dimensional stability. In other cases, certain materials may have to be avoided, and in still others it may be possible to find new ways of minimizing the ill effects of dimensional change.

Thermal Expansion

The dimensional changes in materials brought about by changes in temperature are well known. Thermal expansion is to a large extent inherent in materials and is not normally subject to much adjustment through modifications to the materials. The effects of thermal expansion in building construction are not nearly so well recognized as they ought to be, particularly in Canada where the normal ranges of temperature are relatively very great. Materials exposed to the weather may experience a range of temperature of 140° in many parts of Canada. It is not difficult to demonstrate by calculation that a 20-foot spandrel beam, for example, will change in length by one-eighth inch upon a temperature change of 70° and that if this deformation is fully restrained, as it might tend to be in a long steel structure, the corresponding axial stress that could be developed is 14000 p.s.i.

Serious stresses resulting from restrained thermal expansion are not confined to steel structures. Temperature variations throughout a plain 8-inch masonry wall for ex-

Fig. 1



Yearly temperature throughout a solid masonry wall for air temperature range — 40° to + 95°

treme Canadian winter and summer conditions are shown in Fig. 1[1]. The variation in outside surface temperature is 133° and the potential change in length for concrete is 1.1 inch in 100 feet. If fully restrained the corresponding stress developed in a normal concrete would be about 2300 p.s.i. The gradient in temperature is largest in winter, being about 7° per inch. Under conditions of no restraint this would result in a camber of 2.2 inches in 50 feet of height or length of a wall initially plane, and if restrained would result in a stress in normal concrete of about 1000 p.s.i.

Fitzmaurice[2] gives figures on the magnitude of the stresses likely to be produced in walls of various brick-mortar combinations with restrained thermal expansion. The stresses for a 27°F rise in temperature (15°C) are shown to be from 6 to 14 per cent of the failing stress in compression, the highest value being for strong brick in cement mortar. Somewhat similar results can be expected for stone masonry. It need hardly be emphasized that temperature changes and temperature gradients will lead to cracking of masonry under Canadian conditions.

This situation in respect of thermal expansion which has been dealt with at some length is quite similar in many respects to the situation created by other dimensional changes which are now to be discussed.

TABLE I‡
THERMAL AND MOISTURE EXPANSIONS OF VARIOUS MATERIALS

	Thermal expansion % length change for 100°F	Expansion on wetting % length change	Modulus of elasticity x10-6
Limestones	.01 to .05	.002 to .01	3 to 10.4
Clay and shale bricks	.02 to .05	.002 to .01*	1.4 to 5
Concrete	.05 to .08	.01 to 0.2**	2.5
Steel	.067		30
Portland Cement Mortar	.04 to .06	.005 to .028	3.5
Lime Mortar	.04 to .05	.001 to .019	.5

*Highest expansions with soft burned bricks
**Depends greatly on aggregate. Lightweight aggregates give high expansions.
‡Composite of data from several sources

Dimensional Changes due to Moisture

Almost all masonry materials exhibit dimensional changes with changes in moisture content. The significance of these may be judged from the data of Table I. To assist in this, the thermal expansions are expressed on a basis of per cent change in length for 100°F, and may be compared directly to the expansions on wetting, also given on a per cent length change. It will be noted that the length changes possible upon wetting are appreciably less than those which may be expected from temperature change (100°F) for limestones, clay and shale bricks, and lime mortar, and are greater only in the case of some concretes. The stresses set up as a result of moisture changes will generally therefore be less than those previously indicated for temperature changes, but may still be significant.

The differences in wetting expansion between lime and cement mortars and between cement mortar and clay and shale bricks may be noted in relation to the "compatibility" of bricks and mortar. Volume changes in brick masonry materials were the subject of study by Palmer of the National Bureau of Standards in 1931[3]. He concluded that "differential volume changes between brick and mortar caused by variations in moisture content are apt to be greater than those produced by normal temperature variations".

Initial Shrinkage

Another pertinent dimensional change is that which is likely to occur during the setting and curing of cementitious materials, or of mortars and concretes containing cementitious materials. These shrinkages are much greater than the subsequent changes due to wetting and drying. Palmer found shrinkages ranging from 0.11% to 0.27% for eleven portland cements made up in 1:3 mortars, and from 0.30% to 0.55% for 1:3 lime mortars.

Initial shrinkages may be expected to vary widely, depending on mixes and curing conditions.

Freezing Expansion

Still another important dimensional change occurs when masonry materials are frozen while wet. It is interesting to note that the less durable materials exhibit the greatest expansions, and that expansions of the order of 0.02% were found by Palmer to result from 20 cycles of freezing and thawing for certain soft or under-burned bricks. The results for a number of these which were disrupted by the treatment were not included in the figure given.

Thomas[4], working in England with building stones, has also studied the deteriorating effects of freezing of wet materials and has demonstrated that the degree of saturation at the time of freezing is of importance.

Absorption of Water

The extent to which masonry materials will absorb water has long been recognized as an index in their assessment and many specifications set limits upon permissible absorption. More recently attention has also been directed to the importance of degree of saturation, of concern in freeze-thaw deterioration, and to initial rate of absorption which is of primary interest in the case of bricks.

All common masonry materials contain some amount of void or pore space within them. This can be a small percentage of the total volume of the material as in the case of some dense building stones or a relatively high percentage as in the case of many clay bricks and building stones. The ease with which this void space can be completely filled with water varies with the material and with the conditions to which it is exposed. It is now known to be very difficult to achieve perfect saturation although this can be

[1] Hutcheon, N.B., Fundamental considerations in the design of exterior walls for buildings. National Research Council, Division of Building Research, Ottawa. NRC No. 3057. 1953. 25p.
[2] Fitzmaurice, R., Principles of Modern Building, Vol. 1, Walls, Partitions and Chimneys. Department of Scientific and Industrial Research, His Majesty's Stationery Office, 1938.
[3] Palmer, L.A., Volume Changes in Brick Masonry Materials. U.S. Department of Commerce, National Bureau of Standards, Journal of Research, Vol. 6, 1931.
[4] Thomas, W.N., Experiments on the Freezing of Certain Building Materials. Department of Scientific and Industrial Research, Building Research Station Technical Paper 17. London, H.M.S.O., 1938.

approached in the laboratory by first evacuating the air, or, in a more practical way, by boiling.

The range of absorptions of Canadian bricks from three sources are given in Table 2. Also shown is the initial rate of absorption, expressed as the grams of water taken up through 30 square inches of brick face immersed one-eighth inch in water for one minute, and the "saturation coefficient" which is the ratio of the absorption on the cold and boiling tests.

TABLE 2[5]
BRICK ABSORPTION PROPERTIES

		Initial Rate of Absorption or Suction (grams/30 sq. in.)	Absorption on total immersion 24 hours (% dry weight) C	Absorption on total immersion in boiling water 5 hours (% dry weight) B	Saturation Coefficient C/B
Brick A					
(dry press shale)	(1)	54.5	6.2	8.5	0.73
	(2)	104.7	8.7	11.5	0.75
Brick B					
(extruded shale)	(1)	2.2	0.9	2.4	0.41
	(2)	6.0	3.6	5.2	0.71
Brick C					
(extruded clay and	(1)	35.2	12.5	15.1	0.83
shale)	(2)	41.9	13.4	15.8	0.85

Samples (1) and (2) of same lot of bricks show range within the lot.

Durability under Freeze-thaw Conditions

The extent to which a material is damaged in freezing is known to depend on a number of factors, which include its degree of saturation with water when frozen, the rate and number of times freezing, the strength and elastic properties of the material and the nature of the pore structure of the material. Thomas found for a number of stone samples that there was a degree of saturation in each case below which no damage from a single freezing could be detected. These limiting saturations covered a range from 71 to 90%.

For present purposes the mechanism of damage may be considered to be due simply to the expansion of water to the extent of about 9% by volume upon freezing. This sets up stresses in the material which may weaken it or even disrupt it. The larger the proportion of unfilled pore space at the time of freezing the less likely are these stresses to be developed. Actually there are other complicating factors to be considered, such as the lowering of the freezing point of water when dispersed in fine pores, and the plastic nature of ice which causes it to flow under load if given sufficient time.

Freeze-thaw durability is measured in the laboratory by noting the progress of the deterioration as the material is subjected to repeated cycles of wetting and freezing. There cannot yet be said to be a universally accepted standard for this determination, and much work must be done in standardizing this test and in correlating the results with service conditions. Despite this, the freeze-thaw test is now accepted as a basis for the standard brick specifications of ASTM and of CSA, and for the evaluation of concretes.

Different degrees of severity of exposure of bricks in regard to frost action are recognized in both ASTM and CSA specifications and bricks are classified in three grades, "SW", "MW", and "NW", providing different degrees of resistance.

Grade "SW" bricks are intended for use where high degree of resistance to frost action is desired and the exposure is such that the brick may be frozen when permeated with water.

Grade "MW" bricks are intended for use where exposed to temperatures below freezing but unlikely to be permeated with water; as a typical example, brick used in the face of a wall above grade.

ASTM grade "NW" bricks are intended for use as backup or interior masonry, or if exposed, for use where no frost action occurs.

The basis of these classifications is the reaction of bricks to a standard freezing and thawing test, in which the saturated bricks are frozen and thawed, under certain conditions, 50 times. Bricks which are virtually unaffected by this treatment are classed as grade "SW"; if certain slight changes occur in bricks from the treatment, they are classed as grade "MW". Disintegration of the bricks by the freezing and thawing treatment places them in the grade "NW".

Since a correlation between the properties of bricks of "saturation coefficient", compressive strength, and water absorption and the reaction of bricks to a standard freezing and thawing treatment of 50 cycles has been determined, it is possible on the basis of these properties, to classify bricks into the ASTM grades. This enables comparatively quickly made measurements to take the place of the relatively long freeze-thaw treatment, and an indication of the frost resistance of the bricks is obtained.

Moisture Migration

Since the effects of moisture in materials are of such importance in determining their performance there is a need for understanding the ways in which moisture may enter, migrate in, and leave a material.

Water can enter and move within a material only under the influence of some potential. It follows that water held in a material at a given concentration must be at a given potential or free energy level. When a material is saturated at atmospheric pressure, the potential, or free energy level, is the same as that of free liquid water at the same temperature. Water held in a material under conditions of partial saturation is therefore at some definite but lower level of potential. The forces to hold water in a material at such a depressed level of potential, relative to free water at the same temperature, may be provided by several kinds of forces, including surface and capillary forces acting on water within the material. It is sufficient for present purposes to note that these potential or energy levels can be described and measured for various conditions of temperature and moisture content for a particular material.

If two pieces of the same material, one wet and one dry, are placed in contact there will be a movement of moisture from one to the other until the potentials are equal. Similarly if water is put on one end of a piece of dry material it will gradually distribute itself until the potentials throughout the piece of material are equalized. When two

[5] Ritchie, T. and H.R. Meincke, Capillary absorption of some Canadian building bricks. National Research Council, Division of Building Research, Ottawa. NRC No. 2966. 1953. 16 p.

pieces of different materials are put together the same thing will occur, but the final moisture contents need not be equal though the potentials are. The relationship of the moisture contents will then be determined by the particular potential versus moisture content relationships for the two materials. It is quite possible, for example, to have a brick containing 1% moisture by weight in contact with mortar containing 9% moisture by weight without any flow between them.

Water contained in the air as vapour has various potential levels depending on the degree of saturation, usually described in terms of relative humidity at a given temperature. As is well known, moisture will evaporate from a piece of material saturated with water to the air surrounding it so long as the air is not also saturated with moisture. In this case the moisture leaves the material as vapour but may move to the evaporating plane either as liquid or as vapour, or both, depending on the conditions. When caused to move in a material in this way, the liquid water present can dissolve and carry any salts which are present. Upon evaporation of the liquid water at or below the surface these salts may be deposited.

Potential levels of moisture are also changed by temperature, so that if a piece of material containing water is heated at one end, creating a temperature gradient, water may be caused to flow within the material in the direction of lower temperature. Migration under these conditions occurs, so far as is known, at present, in the vapour state but may be followed by condensation reducing the moisture to the liquid state within the material if the conditions are suitable. Migration of vapour, under a temperature gradient, leads to differences in moisture content throughout the material, and may therefore be accompanied by a liquid movement as well, which may assist or oppose the vapour movement, depending on the conditions.

Some Effects of Moisture Migration

One of the most commonly observed effects of moisture migration is that of the appearance of efflorescence on brick masonry. When conditions are suitable, moisture which has entered the masonry is caused to migrate to the surface as liquid and be evaporated there. Soluble salts already present within the masonry are dissolved by the liquid water present within the masonry and are carried by it and deposited at the evaporating surface. Four things are essential for efflorescence: soluble salts within the masonry, water within the masonry, conditions for migration of liquid to the evaporating surface, and conditions producing evaporation at the surface. The elimination of any one of these will eliminate efflorescence.

Salts which have appeared at the surface are not always readily eliminated by washing or by rain since some of the water reaching the surface initially will be absorbed by the masonry, but will in the meantime have redissolved much of the salt and have carried it back into the masonry

Even more serious effects are believed to be possible to appear again later when conditions are suitable.
when under conditions similar to those which produce efflorescence, the evaporating plane occurs within the material. Forces may then be produced by the salt crystals growing within the material as the water is evaporated which are capable of disrupting the material and causing it to spall. This effect is not unlike that produced by wetting and freezing and it is difficult to tell in many cases which mechanism may have been responsible for spalling of a material.

The application of surface coatings may frequently create conditions resulting in the creation of an evaporation plane beneath the coating, or even within the base material. In the former case, the coating may eventually be forced from the surface by crystal growth, and in the latter, the surface material may be caused to spall, carrying the surface coating with it. It is most likely that many cases of failure of surface coatings are due in part to crystal growth. Of particular concern to some of the workers in this field is the possibility that silicone type surface waterproofers may create spalling conditions. They may stop the movement of liquid water on its way to the surface and force evaporation to take place at a plane within the material, at a distance from the surface determined by the degree of penetration of the surface treatment.

Surface treatments may also lead to complications in another way, by promoting wetting-freezing effects. The application of a coating which seriously interferes with the passage of water vapour may force condensation of water vapour behind the coating and may lead to a high degree of saturation of a surface layer of the base material immediately beneath the coating so that upon subsequent freezing the material is caused to spall. This is believed to be the reason for the serious surface spalling which frequently occurs following the application of oil paints to brickwork. It seems entirely possible that wetting by condensation behind a moisture barrier under temperature gradient conditions will produce a high degree of saturation, which is a condition conducive to disruption by freezing. Further, the saturation is produced close to the surface where freezing can occur readily.

Conclusion

Attention has been drawn to a number of pertinent properties and characteristics of building materials which the designer may presently consider usefully, as well as to a number of other considerations with which little guidance can yet be given. Water is seen to be the great complicating factor which must be studied and understood in dealing with many problems involving stability and durability of building materials.

The above was a paper read at the Annual Assembly of the Royal Architectural Institute of Canada in June, 1955.