Water and building materials
Latta, J. K.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000829
Canadian Building Digest, 1962-06

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 30

Water and Building Materials

Originally published June 1962

J. K. Latta

Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

It has sometimes been stated that there would be no need for building research were it not for the effect of water in the wrong places. This statement, like all such sweeping generalizations, is an over-simplification and cannot be entirely supported. Nevertheless, the harmful effects of water on building materials can hardly be over-emphasized. If they did not exist, the construction of durable buildings would be greatly simplified and the task of the designer made much easier. This Digest is intended to draw attention to these destructive mechanisms and to give a brief account of some of the phenomena involved.

Dimensional Change

With a change in moisture content many building materials show considerable change in dimension, the magnitude of which may be greater than that caused by normal temperature variations. Thus, if a material takes on water at one period and releases it later, there will be a continuing expansion and contraction that may lead to the destruction of the material; or alternatively that may break it loose from surrounding materials. Table I lists the percentage change in length of various materials on immersing a dry specimen in water, together with the thermal expansion for a 100 F deg temperature rise for comparison.

Table I Thermal and Moisture Expansions of Various Materials

	Thermal expansion per cent length change for 100F deg	Expansion on wetting per cent length change	Modulus elasticity $x10^{-6}$
Limestones	0.01 to 0.05	0.002 to 0.01	3 to 10.4
Clay and shale bricks	0.02 to 0.05	0.002 to 0.01*	1.4 to 5
Concrete	0.05 to	0.01 to	2.5

	0.08	0.2**	
Steel	0.067		30
Portland cement mortar	0.04 to 0.06	0.005 to 0.03	3.5
Lime mortar	0.04 to 0.05	0.001 to 0.02	0.5

* Highest expansions with soft burned bricks.
** Depends greatly on aggregate. Lightweight aggregates give higher expansions.

Differences in wetting expansion between lime and cement mortars and between cement mortar and clay and shale bricks should 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. 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."

Similar differential dimensional changes, with change in moisture content, can take place in two materials bonded together. A warping effect may be produced similar to that produced on a bimetallic strip by changes in temperature. Precast concrete panels, for example, which have a facing material of a composition different from the backing, may be subject to such warping. A differential moisture content through the thickness of a homogeneous material will also have a warping effect, since the side of higher moisture content will expand more than that of the lower. Such a differential moisture content can be produced by vapour migration or by having the opposite sides exposed to different atmospheric conditions. Rain absorbed on the outer face of a material will have a similar effect.

Corrosion

Corrosion in buildings was discussed in **CBD 20**, where it was explained that it is largely an electrolytic action in which an electrical potential causes a current to flow, provided that there is an electrolyte to complete the circuit. This electrolyte is provided by any water that may be present in the building assembly from various sources. The electrical potential can be provided by two dissimilar metals or by one metal if there are salts in the water. Even with pure water corrosion can take place if oxygen is present to combine with the hydrogen generated and thus remove it, permitting the action to proceed. As with many other destructive agents other phenomena must be present with the water before corrosion takes place, but without water the material will not corrode.

Decay

The rotting of wood is another destructive phenomenon that requires water to enable it to proceed. Rotting is caused by the growth of fungi in the wood tissue and for this to take place several conditions must be satisfied. There must be food for the fungus to feed on, and this is provided by the wood itself. There must be air; and if the wood is completely submerged the air supply is cut off and the decay will be stopped. The temperature must lie within a certain range. Near freezing point the fungus will become dormant, although it will not be killed even by very low temperatures; above 100°F it may also become dormant but will not be killed until a temperature of over 140°F has been reached. The optimum range within which decay will take place is between about 70 and 90°F. Finally, moisture must be available in excess of the fibre saturation point of the wood. With many woods this point is reached at about 27 to, 30 per cent of the oven-dry weight, but because of variations in the moisture distribution in the wood it is usually accepted that less than 20 per cent moisture content is needed to stop rotting. Indeed, once they are established some fungi will produce their own source of water; others can spread tendrils for quite long distances over steel and other materials in order to reach a source of water. The only completely effective means of preventing wood from decaying is to, keep it either dry or completely saturated. The food source can be poisoned by the use of wood preservatives, but in most cases these will only be effective in a comparatively thin layer on the surface, which may be subject to damage that can let the spores of the fungus into the untreated inner core of wood, This should not be taken to mean that a preservative is not a useful additional protection in cases where it cannot be guaranteed that the wood will remain dry.

Blistering

When laying a built-up roof every precaution must be taken to prevent water from being trapped either between the plies or underneath the membrane. Should water become trapped and vaporized with the heat of the sun, there is danger of the formation of a blister in the roof; although passages can be provided through the insulation to relieve the pressure if the water is below the entire membrane. Such pressure relief passages cannot be provided between plies of roofing felt, however, and water trapped in the thickness of the membrane will almost inevitably raise a blister and may also cause the roofing felts to rot. In any case, the presence of water will weaken the bond provided by the bitumen and so reduce the waterproofing properties of the roof. Blisters in paint applied over damp wood, or wood which absorbs moisture because of vapour flow, are formed in a similar manner.

Efflorescence

Water that moves through a material in a liquid state can also produce many harmful effects. The most obvious is the efflorescence that often disfigures the face of a building. Migrating water dissolves salts from some position inside the material and then deposits them on the surface as the water evaporates. Usually this effect is not destructive but merely disfiguring. If a vapour-permeable but water-repellent membrane is applied to the outer face of the wall, however, the water may be caused to evaporate from behind it, so that the salts are deposited behind the surface layer and the resulting force of crystallization can cause the skin to spall. The subject of efflorescence has already been dealt with at considerable length in **CBD 2** and need not be examined further here. It should be noted, however, that the spalling produced by the crystallization of salts behind the surface of the material is very similar in appearance to that produced by frost action, and in many cases it is difficult to determine which mechanism has caused it. Surface treatment of masonry may promote further complications if it restricts the escape of vapour that is migrating from inside the building. This vapour may be forced to condense behind the surface and lead to, trouble under freezing conditions.

Leaching

Liquid water moving through concrete and mortar can cause a steady deterioration of these materials by leaching out the calcium from the calcium silicate bonding materials. This action is most pronounced with soft or mildly acidic waters such as are found in reservoirs fed from swampy areas. Very often this water percolates through the dam at the level of the concrete lifts and runs down the downstream face where it evaporates, leaving a white deposit. A similar deteriorating effect has been seen in buildings such as paper mills where the high humidities cause water vapour, which passes into hollow concrete roof beams and condenses in the colder upper parts. The pure condensate may have absorbed carbon dioxide from the air and become slightly acidic. As the water migrates within the beam the calcium compounds are dissolved from the cement and in many locations have been left, after the drop of water bas re-evaporated, as stalactites of calcium carbonate. The undersides of such beams were seen to have no cementing material left and were covered with loose sand that could be brushed off by hand. Similar effects may be seen where rainwater percolates through concrete bridges and abutments and on the faces of buildings where it has entered behind facing stones and reappeared lower down, carrying with it calcium compounds from the mortar or backing concrete.

Freezing

The most striking feature of the Canadian climate is the long period of very cold weather that affects many parts of the country during the winter. It is often considered that cold temperatures are responsible for much of the destruction that takes place in a building envelope. In actual fact, however, cold temperatures do not of themselves have any very serious effect on the materials. Naturally, the large temperature range between summer and winter will cause large expansions and contractions, but usually these can be allowed for by means of suitable expansion joints. On the other hand, the effect of freezing conditions in conjunction with water can lead to a very rapid deterioration, and under extreme circumstances one freezing may be enough to shatter the material. The way in which destruction takes place is complex, but it is known to depend upon a number of factors that include the degree of saturation with water, the rate and number of times of freezing, the strength and elastic properties of the material, and the nature of the pore structure in the material.

One of the mechanisms producing frost damage is an ice lensing action in which ice crystals tend to draw water from warmer regions in a manner similar to that causing frost heaving in soils, as described in **CBD 26**. As evidence of this mechanism, planes of weakness have been observed in both the field and the laboratory in concrete subjected to freezing and thawing, and ice lenses have been found in pavement concrete destroyed by frost action. Similar destruction has been produced by organic liquids that contract on freezing. It has also been found that ice lenses can be built up in mortars and backing materials to building stones and that they can force the stones away from the face of a building in a very short time.

It is also possible for the expansion of water, on turning to ice, to cause destruction. This situation occurs when the water in a completely saturated macropore freezes rapidly and the excess water must flow away through the capillaries. If these capillaries are too fine to permit sufficient flow quickly enough, relative to the speed of freezing, a pressure will be built up which may fracture the material. This mechanism may give rise to the situation whereby dense concrete, for example, may be destroyed by a complete disintegration throughout its depth; whereas with a weaker and more porous concrete destruction may result from a steady spalling from the outside. Regardless of which mechanism is acting, the force produced will set up stresses in the material that may lead to its destruction if they are not relieved. In some instances, the elastic properties of the material will provide the necessary outlet, but in most cases it must be provided by spaces within the material into which the ice or water may expand.

Most building materials have a number of voids and pore spaces in them. If these are completely filled with water, there is no space left to accommodate the expanding ice and the material may be ruptured at the first freezing. As the quantity of water in the material is reduced, more and more space is provided to absorb the expansion, and it is found that below a certain degree of saturation no damage occurs. With stones, this limiting saturating covered a range of 71 to 90 per cent of complete saturation. It follows, therefore, that if a material can be fully saturated only with considerable difficulty, then there is a much greater chance that the critical degree of saturation will not be reached. The ease with which the pore and void space can be filled with water will vary with the material and the conditions to which it is exposed, but in practice materials are seldom, if ever, completely saturated. The ratio between the amount of water absorbed by a material after being totally immersed in cold water for 24 hours and in boiling water for five is known as the "saturation coefficient," and is of great use in estimating the resistance of materials such as brick to damage under freezing conditions. A low saturation coefficient indicates a large number of unfilled voids and a high resistance to damage on freezing; a high coefficient, few unfilled voids and a low resistance. The absorption properties of three different types of brick are given in Table II.

Table II Brick Absorption Properties

	Initial rate of absorption	Absorption on total immersion	Absorption on total immersion	Saturation coefficient

	or suction (gram/30 sq. in.)	24 hours (per cent dry weight)	in boiling water 5 hours (per cent dry weight)	
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 shale)	(1) 35.2	12.5	15.1	0.83
	(2) 41.9	13.4	15.8	0.85

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

The distribution of water and the nature and distribution of the voids will both, however, have an important bearing on the resistance of a material to damage by freezing. Since concrete made with a high water/cement ratio is relatively porous it might be thought that such concrete would have good frost resistance because of the voids left as the water dries out. Unfortunately the capillary system developed holds water strongly and does not provide suitable relief spaces. Entrained air, on the other hand, leaves pores of such a size that they are not readily filled with water, thereby providing spaces within which the ice lenses can grow. Thus the pressures that might be developed are reduced and air-entrained concrete has higher resistance to destruction under freezing conditions than has non-air-entrained concrete.

Aesthetics

The destruction of building materials and assemblies is a most serious consequence of water in the wrong places, but no account such as this can be considered complete without some comments about its disfiguring effects. Efflorescence has already been referred to and is one such effect, but the accumulation of dirt on damp surfaces, which can very quickly mar the appearance of a building, is another. A uniform accumulation over the whole surface is not so noticeable as concentrations of dirt in localized spots, so that it is most important that all water running down a face and intercepted by a flashing or a window sill, for example, be thrown clear of the face of the building. All too often streaks may be seen from the ends of projections that have not been given an adequate weathering and a drip on their lower edge. Stains can also be caused by water running over metals and then onto masonry walls. Rust stains are among the more common ones, and may be caused by reinforcement which has not been given adequate cover, or by projecting bolts and other anchorages. Iron and steel are not the only metals, however, that can cause disfiguring marks, for aluminum, and copper also give trouble in this respect, and aluminum window frames in particular are often the cause of streaks below them.

The list of the harmful effects of water in building materials and assemblies is indeed a long one. In many instances the water by itself is not harmful, and only when combined with other phenomena does it cause rapid deterioration. On the other hand, the other phenomena involved will not cause deterioration in the absence of water. It follows then that if water can be controlled a building can be made more durable and the maintenance and repair costs reduced. If this could be achieved only by the use of very expensive materials and construction it could be argued that it is better to let the building deteriorate and to replace the damaged portion from time to time. In fact, however, durable construction can be achieved with relatively inexpensive materials and designs, provided that the designer understands the behaviour of water in its various forms and applies the necessary controls to prevent it from accumulating in harmful quantities.