SOME OBSERVATIONS REGARDING FROST ACTION

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SYNOPSIS

The authors advance the interesting hypothesis that the nature of frost heave in roads, the spalling of concrete pavement, and the disruption of masonry through frost action is substantially the same. It has been established that frost boils and the greater part of frost heaving is a result not so much of freezing of moisture present in any one spot in soil capillaries but of the building up of ice plates through migration of moisture from road shoulders and sub-grade water tables.

The spalling of concrete and masonry may be due not to the freezing of static water within the pores of the mass, but to the building up of ice plates or incipient ice plates due to migration from the warm side. To investigate such a conclusion, a test was devised that duplicated as nearly as possible the natural conditions. As a first step, standard building bricks were tested with one end in water above the freezing point, the other end exposed to a temperature between 0 and 10 deg. F., and the mid-section of the brick surrounded by insulation.

Preliminary tests on a porous brick seem to bear out the assumptions, for the brick spalled quickly near the cold end, producing a clean fracture which was coated with about 1 mm. of continuous ice.

The action of frost on soil masses has long been recognized as a major cause of deterioration of highway surfaces and it has been studied by numerous laboratories and field investigators, particularly during recent years. At the 1938 meeting of the Highway Research Board a very informative session on prevention of frost heave was held and the consolidation of the papers then presented, as published in the proceedings, supplies very interesting reading to anyone with more than a passing interest in the subject. In addition, laboratory investigations, reported from time to time, have served to establish certain principles which may now, it is believed, be taken as fundamental.

Detrimental frost action manifests itself in two main ways. First there is the frost heave in which vertical and, to a lesser extent, horizontal movement of soil-surfaces takes place during the process of freezing. Secondly, there is what is commonly known as the frost boil which often does not appear until after thawing of the road surface has set in. It is characterized by the development either of an isolated eruption or of a comparatively widespread morass. Both of these phenomena are caused by the action of frost in the presence of moisture. Under ordinary conditions mere freezing of sub-grade moisture in situ is not a significant cause of either frost heaves or frost boils. In order that the effect may be appreciable, it is necessary that conditions be such as will allow the migration of moisture from sub-grades or adjacent areas such as road shoulders to build up ice plates at the freezing surface. The migration of water in this way is a recognized physical phenomenon and, other things being equal, it is a function of the capillarity of the medium through which the water must move.

The resultant ice plates may be of a lamellar nature, or they may be the well-known "Jack Frost" needles. In either event greater or less surface movement results. If weather conditions are such that thawing of the frozen soil takes place from the top downward—and this need not always occur—the time comes when there is a frozen and relatively impermeable sub-grade, surmounted by a soil mass containing the excess water resulting from the melting of the ice plates. Thus, is brought about the frost boil.

The conditions necessary to detrimental frost action on soil surfaces are thus, in brief, a supply of water that is free to migrate and a temperature gradient running from above the freezing point of water to somewhat below it. The recognition of these facts—for which we must thank the students of soil phenomena—has, it is believed, more than passing significance to those interested in concrete road construction and also to those concerned with the action of frost on masonry in buildings and other structures. It is recognized that under some conditions concrete highways have been known to spall, and also that some brick and other building units, particularly those of the porous types—although not necessarily all—have characteristically low resistance to frost action.

Frost is also recognized as one of the major reasons why rock formations, whether igneous or sedimentary, are eventually broken down into earthy material. Most of us have been told at a very early age that the action of frost under such circumstances is due to the fact that ice occupies approximately one-seventh more volume than water. The trouble is that when water-saturated materials freeze they sometimes spall and sometimes do not. The laboratory investigation of building units and of concrete materials generally has been largely along the lines of conventional freezing and thawing tests. It is believed that it is a fair statement to make that the results of such tests must be interpreted with a great deal of caution.

The view that it is mere expansion of water into ice that exerts the disrupting effect on a saturated, porous matrix led in early studies to the belief that a more porous body would be more susceptible to frost action. The fact that this was not always true has been explained in some measure by the conception of a saturation coefficient. In other words, certain stones or masonry units, because of their chemical or physical nature or of the structure of their voids, do not become completely filled with water when apparent saturation has been reached. As a result, when freezing occurs there is still room left for the water to expand and no harm is done. Even with this rather elastic provision the forecasting of the behaviour of stone or masonry on the basis of laboratory tests cannot be considered to be very satisfactory. It is probably fair to say that materials that are relatively very dense do show better frost resistance, but this, it is believed, is only part of the story.

In studies that have been made of the deterioration of masonry structures, particularly by the Department of Scientific and Industrial Research in England, some rather interesting observations have been made. For example, masonry monuments and other structures prior to, say, one hundred years ago, were generally laid up in mortars of comparatively high porosity or, more accurately, probably, permeability. In numerous instances these structures have given very good accounts of themselves from the ageing and weathering point of view. However, in recent years it has been observed that when such structures were repointed with dense mortar, the effect upon the unit so bonded was often disastrous, in that spalling immediately set in. The explanation offered was that the spalling was due to migration of soluble salts derived either from the mortar, from the unit, or possibly through the action of atmospheric sulphur gases on calcareous materials; with a permeable mortar the soluble salts tended to migrate through the mortar and, as they crystallized, the mortar spalled off; when a relatively dense mortar was used migration tended to take place through the building unit with the result that the spalling, when it occurred, did much more damage.

It is believed that the concentration of soluble salts in quantities sufficient to disrupt the masonry, is closely parallel to the concentration of ice in similar localities brought about by similar migration.

In parts of Canada where the temperature stays well below the freezing point for several months of the year with only short periods of thaw, it is sometimes possible to remove a brick or a section of stucco from the exterior of a building and find a layer of ice in the interior of the wall. Such ice might originate from rain or snow or from moisture coming through from the inside, reaching its dew point, condensing, and eventually becoming solid. In either case there is an accumulation at what is presumably the "frost line."

Consideration of the conditions bearing upon the weathering of soil masses, concrete road surfaces, masonry buildings and masonry dams and retaining walls, shows that they have in common the factors mentioned above as being necessary to detrimental frost action, i.e., a temperature gradient from above the freezing point to below it, a degree of permeability, and moisture available on the warm side to migrate to the point at which freezing is taking place.

On this basis the criterion of the weathering resistance, so far as frost is concerned, of any material, would not be so much a matter of its porosity or absorption, as of its permeability. As is well known, these characteristics need not necessarily parallel one another. The measurement of permeability is not always an easy task, particularly in ceramic or cementitious products. On the other hand, the most reliable criterion of the suitability of any material for a given purpose is the test that most closely reproduces the sequence of conditions that it must withstand in service in their proper relative magnitude. According to the above reasoning the conditions that should be observed in any test of the stability of a road mass, a concrete slab, or a masonry structure to frost action would be those already outlined.

In preliminary tests made in these laboratories nearly a year ago, the indications were that it would be possible to test building units and concrete specimens in accordance with these conditions. A thermostat was constructed in which one or more brick or concrete specimens could be stood on end and partially immersed in water, the upper end being exposed to the air of a cold room at a temperature considerably below the freezing point. The specimen was surrounded with thermal insulation at the point where it left the water, so that no difficulty was encountered in keeping the water above the freezing point. In this apparatus it was found possible to spall more porous types of brick in the course of less than 48 hours and the formation of an ice plate at the freezing point was plainly discernible.

Some brick failed to break in the test but no quantitative data were available as to the relative permeability of the brick nor was there any information on their behavior in service.