CAUSES AND CURE OF FROST BOILS

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In the first place, there seems to be no common understanding as to just what is meant by the term "frost boils" Two different phenomena are generally included under this term First: A more or less oval hump which may be only a few feet across, or may extend for 30 or 40 feet over its longest diameter, with a rise of as much as a foot above the normal profile of the surface. Second: A general heaving in the center of the road surface, which may extend for hundreds of feet along the surface of the road; but, in general, the difference in elevation is not so marked as in the case first mentioned, and usually the increase in the elevation of the surface, due to this class of heave, is at a maximum on the center line These two manifestations of frost action are due to the same cause, but are influenced by somewhat different factors They both may be properly termed frost boils.

In many cases the term is more loosely applied to a comparatively thin surface of road metal, which has been broken through to a semi-liquid soil, just underneath the top crust, which is held in place and from which drainage is prevented by a frozen layer of soil directly beneath and about this liquid mass This condition may or may not have been preceded by the heaving so characteristic of a genuine frost boil.

It is quite generally believed by some that this heaving of a road surface in an amount which is very much greater than that very near it, is simply due to the expansive effect of two different classes of soil adjacent to each other With a little thought it is quite evident to anyone that this cannot be the case. If we should assume that the soil in a certain area were absolutely free from moisture and that an area next to it were filled with pure water, the maximum amount of differential heaving which could take place in a 5-foot depth of water would amount to only 5 1 inches, for the volumetric change of water converted to ice is expressed by the ratio 1 0855 This, then, is the maximum amount of heaving which could possibly take place, due simply to difference in moisture content This is evidently quite an exaggerated case, but in many instances the amount of heaving is considerably more than this

If we take into account the fact that the only water which is in the soil is that held in the pore space of the soil, the amount of heaving possible due to difference in soil texture and moisture is still further reduced. Research carried on by the Research Division of the Michigan State Highway Department during the winter of 1927 indicated that the maximum amount of expansion possible for a given amount of water is that in a coarse sand, and amounts to only about 4 per cent by volume Assuming that all of this expansion were to take place vertically, we could account for only 2.4 inches in the soil which gives a maximum expansibility of freezing If we examine the characteristics of a saturated clay, we find that the expansibility is a great deal less than this for the same per cent of moisture, due to the fact that a large amount of water in the highly colloidal soils is held either in a loose chemical or physical combination, so that it is impossible to freeze the water, even though the temperature be reduced to as low as 78 degrees below zero centigrade The amount of water which fails to freeze in some clays amounts to as much as 60 per cent. The maximum expansibility of a clay is only limited by the percentage of water which it contains up to the expansibility of pure water, since a clay may be in suspension in water in almost any degree of concentration Practically, however, the percentage of moisture in clay would rarely exceed 70 per cent under the conditions with which we are usually concerned The expansibility of this clay is about the same as that of the coarse sand, with only 30 per cent of water, viz, about 4 per cent It is, therefore, quite evident from the foregoing that we must look to some other explanation of frost heaving than a simple difference in expansion between two soils of different moisture content.

The only way in which this heaving can occur, in the amounts which are very frequently observed, is by the addition of water from some source after the ground is already frozen This water must be restricted from draining away from the affected spot and must freeze before drainage can be effected There is then a continual addition of water to the soil which is already frozen. The addition of this water may be effected in several ways It may come, first, from the water contained in the soil itself from the freezing of ice in the capillaries; second, it may come from an actual water flow under hydrostatic head through porous soil near the frost heave; third, it may come from the thawing of ice underneath the pavement and flow to the affected place by gravity. However the additional water is supplied, the primary cause is always an obstruction to further flow This obstruction may be due to a change in soil texture, which slows up the flow of the water beneath the pavement so that it freezes before it drains away. In low temperatures the obstruction may be due to ice formed only a short distance from the source of supply This supply may be either gravitational or capillary

The formation of ice by the freezing of water in the capillaries of heavy soil is described by Dr George J Bouyoucos in the Journal of Agricultural Research, Volume 24, No. 5, page 429:

"When the soil is very moist, and the freezing process is not too rapid, the moisture freezes at the surface of the soil, in the form of ice capillary columns, or long needle-like crystals The force of crystallization seems to pull the water from below and bring it to the surface where it freezes into these massive ice capillary columns or compact, needle-like crystals The ice capillary columns would be formed at the surface of the soil without penetrating the lower depths growing up as straight needles or thin capillary tubes massed together The growth seems to take place at the lower end and pushes the entire column upward, as the capillary tubes are elongated from below The ice column shown in Plate 1 is about 4 inches thick and was formed during three nights The formation for each night is indicated by the lines or layers seen in the column

"As previously stated, the water which went to make this 4-inch column of ice, came from the capillaries of the soil, at a lower depth, and was brought to the surface by a pull or force of crystallization From these results, it is easily understood that it is possible for the moisture to move from the fine capillaries and from round the particles as films, to the larger capillaries of the soil short of saturation"

It is quite evident, from the quotation, that an amount of water transferred through a frozen soil can be quite large That a heave is caused from the addition of water to the frozen soil is quite evident from the fact that as soon as thawing and subsequent drainage has taken place, in general, the surface of the soil goes back to its original position

In order to show the direction and distance which a particle of water will move on the surface of a crowned subgrade, the study shown on Figure 18 was made. Where the crowned surface is parabolic the particle of water originating near the center of the pavement follows a logarithmic curve to the edge of the parabolic section, and from thence a straight line over the plane section of the subgrade This curve varies with the percentage of grade as shown

For an 18-foot pavement the distance varies from 18.2 feet on a 1 per cent grade to 108.7 feet on a 6 per cent grade It is easily understood then that water seeping down through the surface in the winter will probably be frozen near the center long before it can reach the edge on the steeper grades. This condition can be easily altered by the placing of a porous subbase on a plane subgrade For instance, the travel under a 9-7-9 pavement 18 feet wide can be reduced on a 6 per cent grade from 108 7 feet to 15 6 feet Subbase then permits of the use of a subgrade more favorable to drainage and also reduces the capillarity of the soil directly beneath the slab

It is also quite evident that large amounts of water might easily collect in one place if free flow to the edge were obstructed, especially on the steeper grades The addition of these large amounts of water to a comparatively small area of soil is particularly destructive to pavement surfaces. In the case of rigid pavements, the location of these frost boils is evident the year round from the characteristic cracking which they produce in the surface These heaves are so large in amount at some locations that it is necessary during the later months of the winter to adopt some means to either caution traffic to slow down, or else construct approaches of some bituminous materials, so as to ease off the shock of fast travel over them.

With the non-rigid types, the effect is still more serious In many cases, in order to maintain the road safe for fast travel, it is necessary to build approaches of sand or gravel to prevent accident. Where winter temperatures are low, it is possible to construct these approaches by filling with snow and then watering the snow to form ice approaches. As soon as the thaw comes, the surfaces may be completely disrupted and the soil below the center of the surface is in a semi-liquid state, with a basin of frozen material preventing its free drainage Snow removal makes this condition particularly severe. While the frost does not penetrate as deep underneath the shoulders by the effect of snow ridges, yet thawing does not take place in the shoulders as soon as it does in the center, and we have a trough-shaped basin of ice filled with a nearly liquid material which it is impossible to drain.

The remedy for frost boils is, of course, the drainage as soon as possible This is accomplished in a number of different ways. The simplest way is, of course, to take out the soft material, cut a hole through the ice in the shoulder and replace with a porous material through which the water can drain. If the drainage is thoroughly accomplished, little trouble will be experienced the following year Tile drainage, while helpful, is of little value unless accompanied by the use of a porous material through which the water can reach the tile and in which the capillarity has been materially reduced. In some cases dynamite has been resorted to, to break up the frozen layer beneath the wet soil and provide drainage The same result is accomplished by the use of a steam jet, in order to thaw a hole through the frozen soil and permit of drainage It is difficult to see how either of these two methods would be practical in a heavy soil which would not permit of the free movement of water away from the affected area. In some cases the steam jet is forced through the shoulder, so that the water can drain out through the holes left on the withdrawal of the jet This method of use of the steam jet is certainly more logical in heavy soils In a number of cases sand is used to replace the material removed from the center of the road, and this is effective for the time being and can be permanently effective if it is arranged to drain the sand after it is once placed. In order to take care of traffic, plank mats have been constructed and placed on one side of the road over the frost boil Repairs to the other side of the road are then made, and traffic is then shifted to the repaired side In order to be sure of traffic getting through, it is highly desirable that some means be used to insure this

To sum up the entire situation, these frost boils are caused by the transfer of water by some means to a location in which the soil is already frozen, and at which this water then freezes This builds up the amount of water in a given place to a very excessive amount On thawing, this water practically reduces the soil to a liquid If drainage is perfectly free at these points, this transfer of water will be to the drainage system and not to the soil itself. A good thick porous layer, preferably with tile drainage, will cure the situation Stone drains are satisfactory in some of the lighter soil, but in heavy soils, after a few years, their effectiveness is greatly decreased The points at which these frost boils will occur cannot, at the present time, be predicted, but with a more thorough knowledge of soils and the drainage of water through them, it may at some time be possible

BERM MAINTENANCE

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Maintenance of berms is engendered by two causes. First, with respect to the function of the berm as an earth retaining wall, and second, with respect to the berm, occasionally, as an extension of the effective roadway The occasional use of berm space for parking does not entail any considerable depreciation