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FROST BOILS

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To discuss frost boils requires first a clarification of the terminology. The term is loosely used to describe any area that fails to carry the traffic because of soft subgrade with subsequent breakup of the surface and disintegration into a quagmire. The subgrade failure may be due to many reasons of which the two main ones are frost boil caused by melting of the ice lenses in a frost heave, and a spring breakup caused by saturation of a low density subgrade. The physical appearances of both at the time of breakup is similar but the correction of each is different because of the causes. For the corrective treatment to be economical, however, it must be accomplished before paving regardless of the causes of the breakup. Since the true frost boils caused by frost heaving are the most severe and also the most costly to correct they will be discussed first.

FROST HEAVE

In Iowa the general formation of thin ice lenses is common in nearly all the silt and clay soils where the water table is close to the ground surface, or freezing zone. These thin ice lenses produce a rather uniform heaving as shown in Figure 1-b which usually goes unnoticed. Only when ideal conditions exist for thick ice lense formation is the differential severe heave formed, and noticed on a roadway as a frost heave.

During the spring thaw the thin ice lenses which formed the general heaving melt as the ground thaws from both the top and bottom as in Figure 1-a, and add high moisture contents to the soil above the unthawed zone. This produces, together with melt water seepage, a soft subgrade condition in relation to the normal summer subgrade. However, when the thick ice lenses of a severe heave melt they add water contents in excess of what the

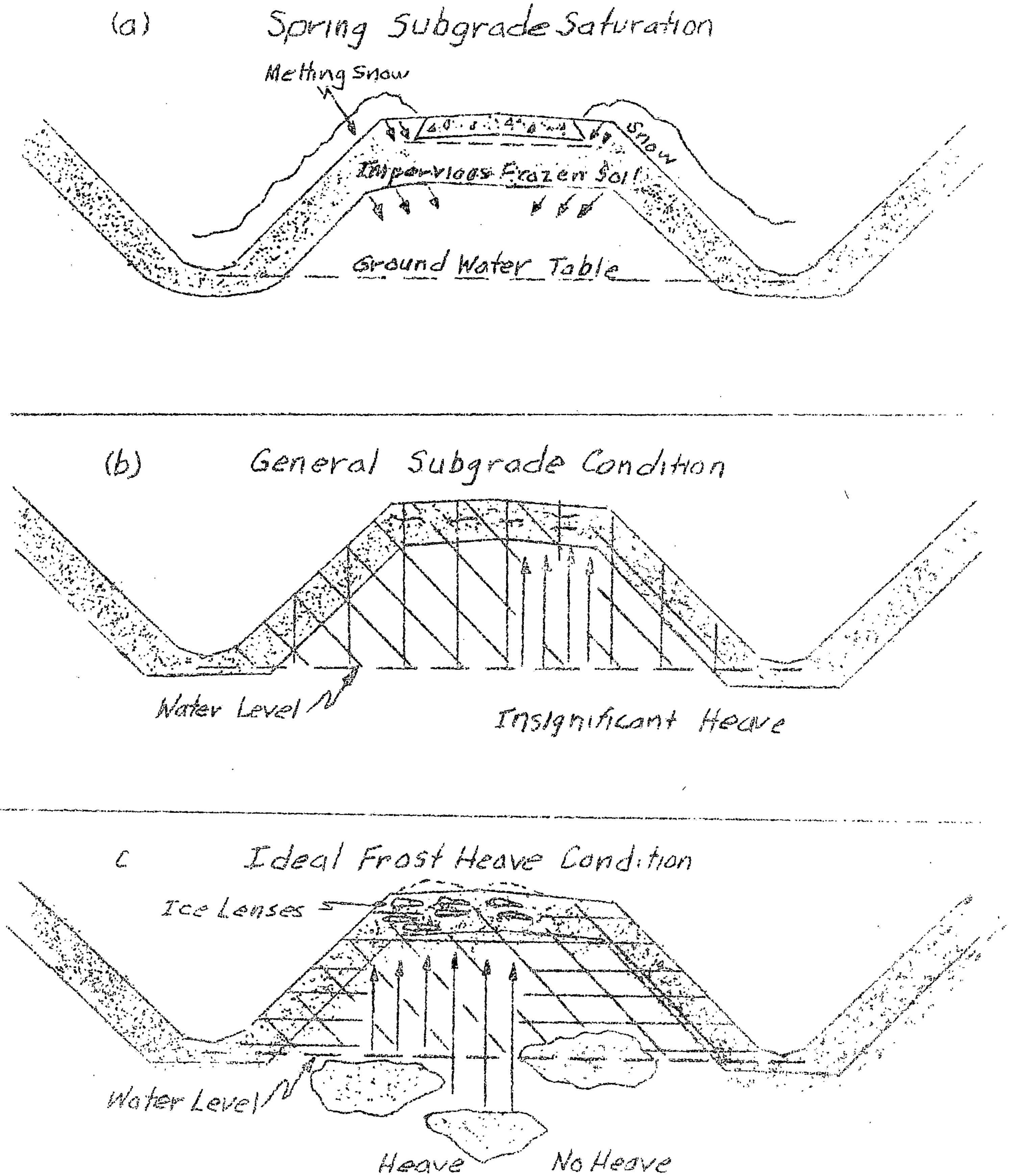

(a) Spring Subgrade Saturation
Melting Snow
Snow
Impervious Frozen Soil
Ground Water Table
(b) General Subgrade Condition
Water Level
Insignificant Heave
c Ideal Frost Heave Condition
Ice Lenses
Water Level
Heave
No Heave

Figure 1

soil can hold, which may even remain pocketed in the thawed soil until wheel load stresses mix them into the soil to form the mud of a "frost boil".

For ice lenses to form three conditions must be met, the more ideally they are met the more severe the heave.

1. Freezing temperatures

   For water to change to ice large amounts of energy must be removed. This lower energy potential at the zone of freezing causes water to flow toward it acting like a "pump" on the capillary tube.

2. Frost susceptible soil

   Almost any soil is frost susceptible but to varying degrees depending on its capillarity and permeability. A soil such as clay may have high capillarity because of the small inter-particle spaces but its permeability is so low that water in quantity does not reach the frost zone, and only thin ice lenses form. Gravel and sand soils may be very permeable but since the particle spacing is relatively large the capillarity is low and the water rises only a short distance. Silt soils on the other hand are relatively permeable and their interparticle spacing is right for high capillarity, thus the water rises in quantity to form thick ice lenses at the freezing zone.

3. Free water source

   Water must be available in quantity for thick ice lenses to develope. A water table must exist within the depth of the soils capillarity to provide free water that can be raised to the zone of freezing through capillary action and energy differential. Although these conditions may exist in a silt-clay soil the amount of free water below the water table is much less than in a sand or gravel soil.

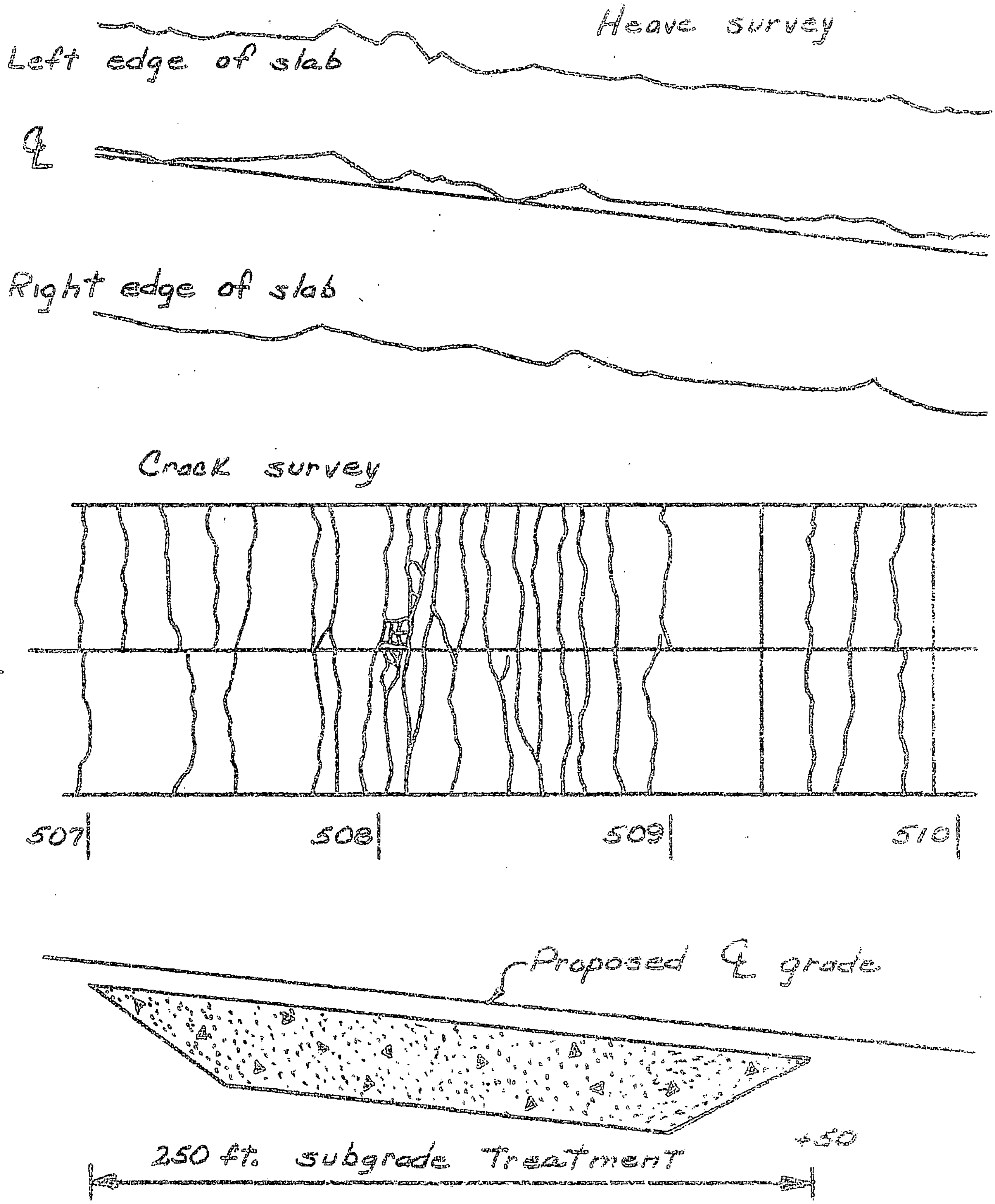
Thus the ideal conditions for a severe heave to occur are found where a sand or gravel pocket holding large quantities of free water is overlain by a silt soil below the free water table and at less than 5 to 10 ft. below the freezing zone, as in Figure 1-c.

The detection of severe heaves which produce the frost boils is relatively easy on existing roads during the winter months following a wet summer. Maintenance personnel can mark the limits of the heaves by visual observation of the vertical distortion on unsurfaced roads as well as paved roads as shown in Figure 2.

On relocation projects the soil survey is the main key to detection of probable frost heave areas. The existence of sand pockets overlain by silty soils in an area where the water table could rise above the sand pocket indicates frost heave potential. An example of a soil survey for a known heave is shown in Figure 3, along with a crack and heave survey.

The correction of frost boils involves the elimination of any one of the three factors which are necessary for thick ice lense formation. If one of the factors are removed or its effect reduced the heave will not occur or at least it will be diminished. Obviously in our climate the freezing temperatures cannot be affected and this factor must be admitted.

The factor which can be removed most easily on unpaved projects is the frost susceptible soil, and this is also the most positive correction. The removing of the frost susceptible silty soil and replacing it with either a nonsusceptible soil such as crushed rock or gravel, (Figure 4-a,) or an only slightly susceptible soil such as a dense glacial clay, (Figure 4-b), to the depth of frost penetration is usually successfuly. If only small silt pockets exist in a clay soil the scarification, mixing and re-compaction of the upper several feet may also be successful since a more

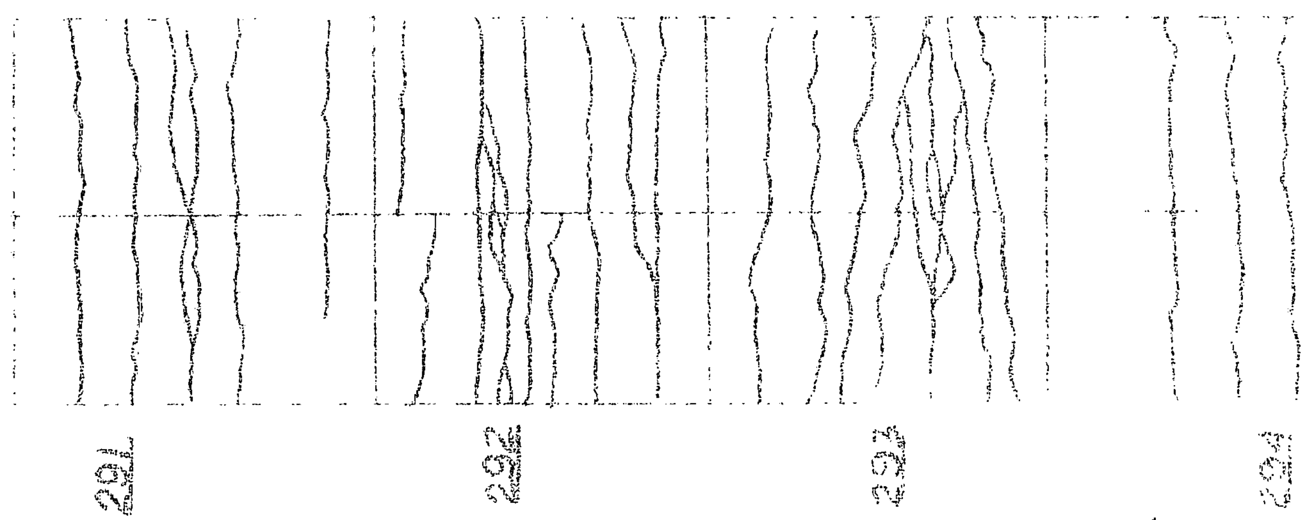


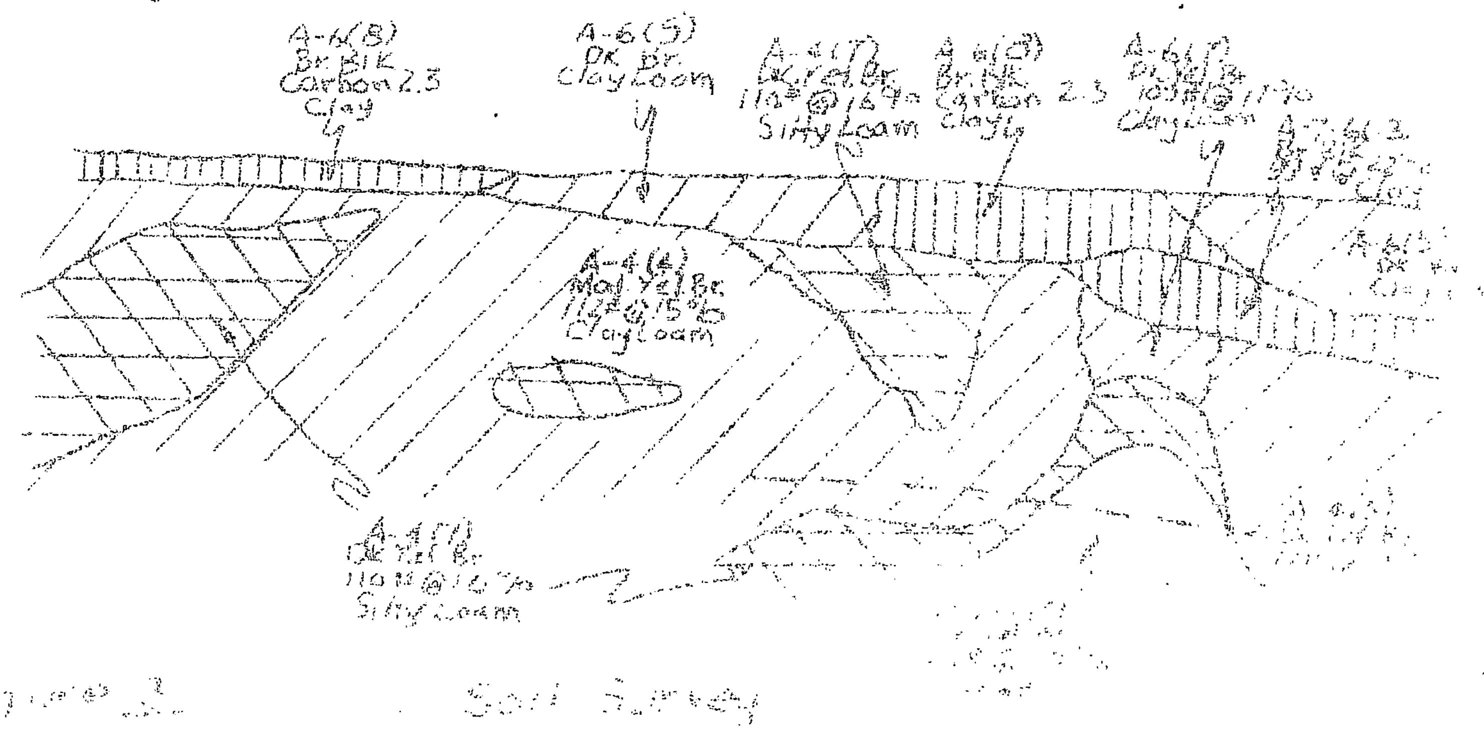
Place below pavement to a depth of 3.0 ft. full width of roadbed approximately (F+20%) 1200 tons of special backfill material. See Art. 4132. Use 50 ft. runouts.

Figure 2

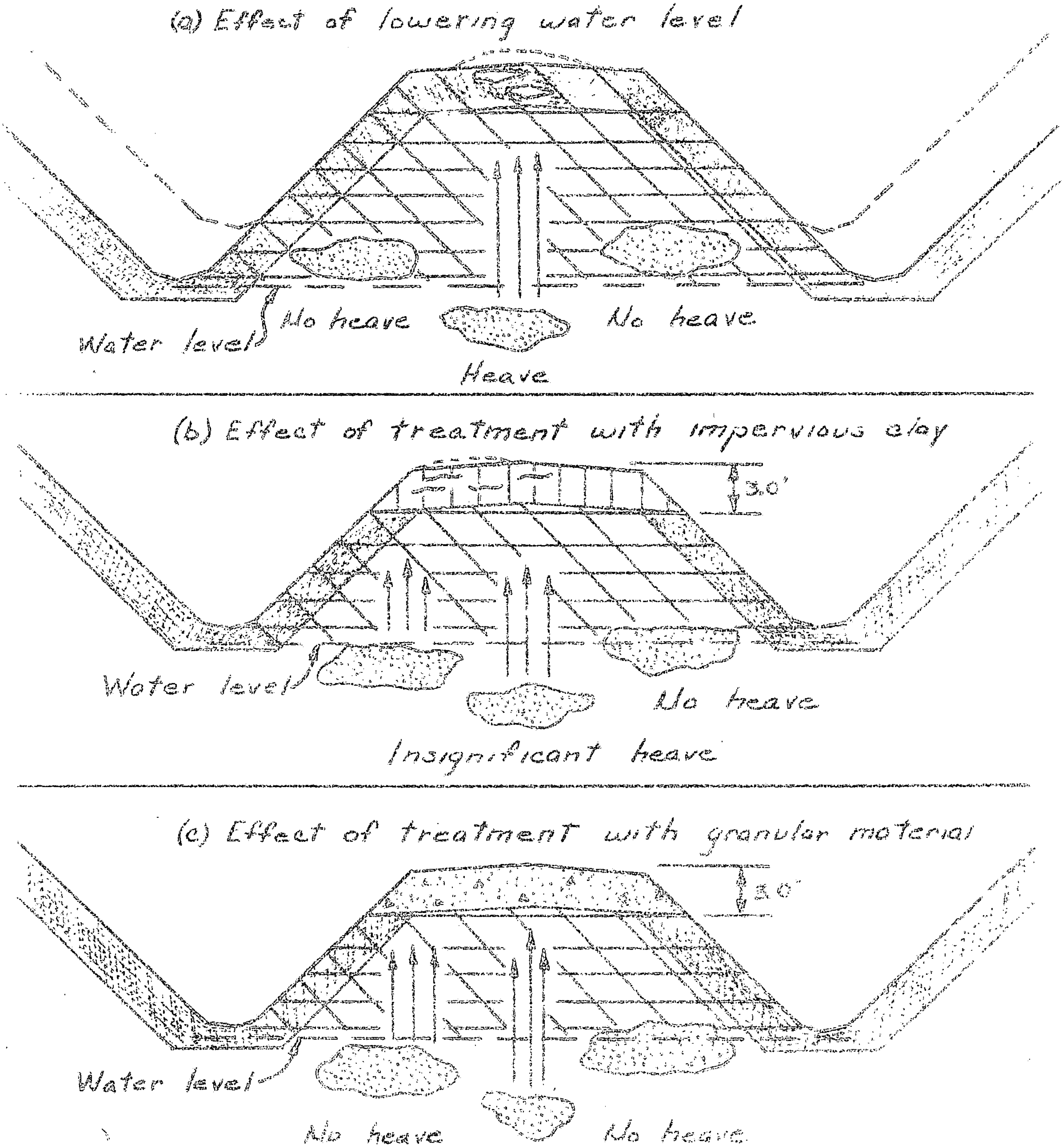
Heave Survey

Crack Survey





Soil Survey



Frost heave corrections

Figure 4

uniform subgrade will not exhibit the differential frost heave, and the permeability will also be lowered.

Removing the free water source factor is sometimes successful in eliminating frost heaves, but it is usually difficult to accomplish. The water table may be lowered by deeper ditches, as in Figure 4-a, or by tiling, pocket and silt interface it will not work. Unfortunately where sand pockets exist they are seldom there singly and usually a series of pockets are involved, some of which may be unknown.

Thus the most successful solution to frost boils is to remove the existing silty soil and replace it with gravel, crushed rock, or a dense glacial clay to the depth of frost penetration. Where non frost susceptible soil such as gravel is used it should be tapered out on each end of the treatment for 50 ft. or so to transition the area of general slight heaving to the area of no heaving in the treatment, as in Figure 2. If this is not done the general heaving will become noticeable at each end of the treatment.

LOW DENSITY SUBGRADE

Probably the greatest cause of spring breakups, which are loosely called "frost boils", is a low density subgrade soil condition. When soil density is low it means that more volume is available in the form of voids that can be filled with water when conditions are correct. In the spring when the frost goes out of the ground it does so unevenly on a subgrade, as shown in Figure 1-a. The frost goes out fastest in the bare center portion of the subgrade and slowest on the snow covered foreslopes and outer edges of the roadbed. This causes a saucer shaped portion of the subgrade to be thawed with frozen impervious soil below it. The slowly melting snow thus has an unfrozen reservoir into which its water seeps, saturating the soil. If the soil is dense it is not only more impervious, but also it can hold much less water than a low density soil. While a saturated dense soil may have moisture contents below the plastic limit and retain its strength, a low density soil may hold moisture contents above the liquid limit and have no strength.

For low density, weak subgrades to exist one of two conditions must have occurred:

1. Poor compaction techniques

A soil with moisture contents in great variation from optimum moisture for compaction will not attain high density when the standard compaction is specified in number of passes per inch of loose thickness alone. Increased passes can compact a dry soil but no amount of compaction will produce high density in a soil that is too wet. All too often the idea prevails that to get the dirt in place is sufficient, and even the specified number of passes is not enforced, much less any concern with the moisture content of the soil. The costs of paving are about 4 to 6 times the cost of grading. The additional costs of good grading over poor grading is the cheapest insurance that can be bought to insure high pavement performance over the years.

2. Uncompactable Soil

Some soils by their physical characteristics cannot be compacted to high density even with the best grading control. Black topsoils because of the porous organic matter have low densities and large void spaces even with special compaction. The use of black topsoils in the upper foot or two or subgrade is certain to produce breakup conditions in the spring or even after slow rains in the summer. A subgrade that can be topped out with inorganic "yellow" soils is certain to give better support than black soils.

Low density subgrade conditions can be detected at almost any time of the year when moisture is in the subgrade following a wet period. They are evidenced by soft, spongy appearance and movement is visible when a heavy wheel load passes over them. In winter an area that is known to breakup in the spring thaw can be observed for frost heaving, and if the heaving is not evident the known breakup area is likely to be caused by low density subgrade soils.

Correction of low density breakup areas is much less expensive than real frost boil areas since the thickness of treatment, when used, need not be as great. The low density subgrade can be removed to a couple feet in depth and recompacted at proper moisture content where the soil is inorganic, or where the soil is black and organic it can be replaced with inorganic soil as a corrective treatment. Naturally if a better quality soil such as glacial clay is available it will produce a better subgrade when compacted and should be used to replace the removed soil.

Conclusions

In conclusion then, the breakups should be detected during the winter and spring by maintenance personnel, and recorded as to location and type by office personnel during the slack season. Correction should be made based on the type of breakup during, or as soon after grading as possible to be sure that all subgrade corrections are made before any paving is contemplated. The costs of correcting poor subgrade conditions on grading or through maintenance after grading, are so small compared with the costs of correcting a pavement breakup that failure to do so amounts to negligence. Public reaction to failures on a newly paved road is unfavorable to say the least.