pavement and flow line is less than 4 ft. above ground water table.

Chimney action at box culverts is not a problem as the roof is usually 12 in. or more in thickness and more than 5 ft. above water table. Pervious material placed for several feet beyond the walls serves to prevent capillary rise from below.

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THE INFLUENCE OF FROST ON HIGHWAY FOUNDATIONS

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It is the purpose of this paper to point out a few of the most frequently encountered types of conditions along some of the highways in the State of New York where damage has been unquestionably caused by frost action, to explain as simply as possible just what seems to have taken place, and to recommend some practical measures which should correct these conditions.

Highways can go bad and wear out from the bottom up, just as well as from the top down. We all know that when only the top wears out there are several accepted and widely used methods of replacement, none of which is excessively costly. But when portions of the foundation bulge under a pavement or bulge and later contract into weak, saturated pockets offering zero support, they usually require extensive repairs which can run into heavy costs.

This problem of highways wearing out from the bottom up is one with which maintenance engineers have long been familiar, and one which both design engineers and construction engineers are coming to recognize. It bears out, more and more, the reason for that most basic of all rules for successful road building and road maintenance - drainage. Stripped of all technicalities, we could almost boil this entire frost problem down to a few simple statements, statements which will hold true regardless of outdoor temperatures, i. e., adequate drainage, no wet subgrade, dry subgrade, no frost heave.

Some heaving will occur whenever there is a concentration of water in the subgrade near enough to the surface to be subject to frost, and it will be observed that the most frequent and most violent frost heaves are generally encountered in pavement built through cut sections. The causes are almost invariably the same - too much water and not enough drainage. A little study of such areas usually uncovers the underlying causes of this condition. Perhaps the ditches are too shallow, or too narrow or both. An honest appraisal, after driving over a few miles of average highways during winter or spring thaws, should be enough to convince any highway designer that most of our road ditches could safely be made deeper and wider. Sometimes the grade of the ditchline could be improved to effect better run-off. Snow banks, pushed back by winter plowing, are very apt to pile up over the ditches. When the atmospheric temperature rises sufficiently, the upper parts of this snow begin to thaw. Meltwater seeps downward to the colder portions along the bottom, freezes again and eventually, as solid ice, fills the ditch. This blocks any possible drainage and the roadway becomes, in effect, a sluice for all run-off not otherwise carried away from farther up the grade. A part of this blocked water, however, has time to seep into the subgrade under the pavement just at the upper transition from fill to cut, and frost heaving is bound to result. Broken and cracked pavements totaling countless miles in extent will attest the frost damage which has resulted from this one condition alone. Or, if surface drainage appears to be adequate, an investigation with augers or probing rods may disclose the presence of unexposed rock ledges just under the bottom of the ditch. These barriers, blocking or misdirecting the flow of groundwater, cause the foundation to become saturated, and frost heaves result. The remedy then calls for cutting through this rock and providing proper drainage, either by a deeper open ditch or by tile underdrain. Such treatment should go far towards removing the cause of heaves. It has also been found that an excessive growth of underbrush along the backslopes of narrow cuts sometimes connotes a subsoil so full of roots that it acts like a sponge and defies all drainage attempts. Once this brush is killed and cleared away, these places have been known to dry up and give no further trouble.

Then, there are the problems which arise during the design of proposed new highway construction. When a cut is to be made through an impervious, moisture-retaining soil undercutting to a depth of at least 40 to 60 percent of the normal depth of frost penetration and replacing with a layer of properly drained medium sand has been recommended. If economically feasible, this is the most satisfactory method of dealing with cuts in nondrainable soils. The dry sand layer also serves as good insulation.

Boulders, where embedded in the foundation soil at depths within the range of frost penetration, have a way of working to the subsurface where they eventually cause bumps in the pavement. They may vary in size from a foot or so in diameter to many times larger. Their damaging action is usually first noted in flexible pavements but is evident, sooner or later, in rigid types when the boulders are very large. As far as maintenance is concerned, once a pavement has been built over large boulders, the only remedy lies in their removal. This is a costly operation when the offending boulder is located under a concrete slab. But it can be done. In one New York highway district, this troublesome boulder problem has been met in design by undercutting the proposed pavement area 4 ft. below the finished centerline grade and then backfilling and recompacting. This design method is now their standard practice through known boulder areas. The initial construction cost is raised, of course, but the chances of certain damage to come later from frost-heaved boulders have been largely removed. It would seem as if practices such as these might well come under the heading of "Built-in Foundation Maintenance," and it is the writer's opinion that if the battle against frost damage to our highway pavements is ever to be successfully won, it must be started in the design.

In the northern and eastern sections of New York State, considerable portions of our highways are laid through rock cuts. The foundations under the pavements placed upon such excavations, especially at transitions from cut to fill, may be considered among the most likely points where frost can be expected. Where rock is excavated, it is practically impossible to leave smooth surfaces. The cuts invariably consist of rough, jagged areas full of potential nondraining water pockets. It would seem that much of the future trouble from frost heaves in these spots could be avoided if more attention were paid to such rough surfaces before permitting backfilling. In no case should spalls or other rock excavation litter be used for leveling, and care should be taken to make the blasted areas as free-draining as is economically possible. One of our highway districts in New York is planning to meet this problem in design by estimating, for these undrainable pockets, a backfill consisting of a fine-grained bituminous mix. Such backfill is to be built up sufficiently with well-tamped layers to form a smooth top-surface gradient which will drain any water seepage from under the pavement. This same district has also had some success in using a low-grade concrete, in lieu of the bituminous mix. It is also recommended that a cushion of run-of-bank gravel, having a minimum thickness of 12 in. be placed between the pavement and this backfilled area. It is believed that if this method of treating rock excavation is followed, there will be a noticeable decrease in the number of frost heaves. It might also be mentioned that wherever transitions are made from rock cuts to fills,in fact, where transitions are made from cuts to fills in any type of material, New York State specifications call for benching to a depth of 4 ft. below finished center-line grade and backfilling with suitable material, properly compacted. Such design would seem to be a factor in lowering the costs which future maintenance would inevitably be compelled to charge against almost certain damage from frost.

The installation of properly placed tile underdrain can be effectively done only after a comprehensive study of the subsoils and ground-water conditions. This applies to the design for proposed construction, as well as to the completed highways where the causes of frost damage to the foundation soil have been recognized as a drainage problem. A study of flow lines under highway sections would seem to indicate that in many instances, tile placed along pavements within 2 ft. of the outer edge, and at a minimum depth of 4 ft. below the center-line grade elevation, should give better protection against moist subgrade and damage from frost than similar tile located under the ditch. This rule is contingent, of course, upon the nature and structure of the underlying subsoils. Any such installations, however, will keep the areas well drained only so long as the system is maintained and continues to function as planned. Because they are seldom properly marked, outlets of subsurface drains often become obstructed due to lack of maintenance. It has been found a good practice to lay a small base under the outlet end of such tiles and to otherwise protect this opening with a little laid-up stone. Some states have small white wooden posts erected to mark these outlets.

A further suggestion for a measure to aid in subsurface drainage for side-hill cuts is to remove the small, excess berm of material which would otherwise remain back of the ditch on the low side of the cut. This extra excavation could be made as a continuation of the shoulder slope down to a point where it intersects the existing surface. In this way, ground-water flow, under a head from the higher side of the cut, is provided a freer access to the surface and subsequent evaporation, leaving just that much less moisture in the subsoil under the pavement. The removal of this berm is recommended only where the sidehill is fairly steep, and where the otherwise remaining backslope would not be more than 4 ft. high.

A high water table, or even one just high enough to be within the capillary range of the foundation soil, is not the only way in which moisture can get under a pavement. Water seeps down through leaky joints in concrete or through cracks of porous macadam pavement. Good maintenance requires that such openings be kept well sealed. Shoulders have a habit of building up near the outer edge and leaving a trough next to the pavement. This depression, actually it may be just a rut or a series of ruts, collects the water from the pavement run-off and lets it seep into the subgrade rather than to follow out and drain into the ditch. Such troughs should be filled whenever possible and the high outer ridge should be scraped down before winter sets in. This problem also brings up a question regarding the advisability of designing, into the shoulders, some thickness of impervious material or waterproof cover to serve as a shelf wide enough to deflect the surface water on out to the ditch. A mixture of fine gravel and bituminous material (about 15 gal. per cu. yd.) spread and rolled into a trench 4 to 6 in. deep and 1 to 3 ft. wide, as a part of the shoulder next to the pavement, has met with success when installed as a maintenance operation.

Still another condition found along our highways each spring, exacting its toil in frost-heaved pavements, is the saturated subsoil caused by blocked side-road and farm-driveway ditches. In the case of the driveways, the existing pipe is often too small, or is plugged, or no pipe was installed in the first place. These spots are usually further aggravated by banks of snow and ice left around the corners by plows. Frost heaves invariably result where the road is located on the low side of such areas, particularly if the foundation material is comprised of finely-grained soil. Culverts, especially the smaller-sized structures, are prone to obstructions, whether of debris, silt and sand accumulations, or ice layers. Once plugged, they become a hazard, causing saturation of the highway foundation. Constant vigilance on the part of maintenance patrol crews is probably the only answer to troubles of this nature.

Field observations provide countless examples of frost damage following the use of silty soils in embankments. This is especially true where such fills have been made over, or near, a convenient source of moisture. It has been a well-established fact that anything which causes a discontinuity of the capillary height will choke off the flow of water and stop the formulation of additional ice lenses in the frost zone. So by placing a layer of gravel between the highest water table and the frost line, the capillary flow is cut off, and aside from the moisture contained in the body of the soil subject to freezing, frost heave can usually be held within reasonable limits. Nor is frost damage resulting from the use of bad soils confined solely to the action of heaving and breaking pavement surfaces. We have recorded instances where silty sand embankments, built around and over concrete structures, such as cattle-passes, have so expanded from frost as to crush the walls inwardly from both sides. Auger borings made at these structures showed the soil in the embankments to be saturated by capillarity to a height of 5 ft. or so above floor slabs which looked perfectly dry at the time of the investigations. The only remedy in these cases called for entirely new structures, and it was obvious that the embankment material at hand was not fit for use as backfill. Present day New York State specifications call for a well-compacted gravel to be placed under and around all such structures, drainage or otherwise, a precaution which should greatly decrease the chances for a recurrence of the damage just described.

It is noticeable that wherever road sections have been built up, that is, where the pavement has been carried along at an elevation of 3 ft. or more above the surrounding terrain, there are few indications of frost damage. This holds true almost invariably, regardless of whether the pavement is of a rigid or a flexible type. It would, therefore, seem that the ideal road section should have its pavement held at just such a minimum raised elevation, be carried above wide, curved ditches through cuts, have wide shoulders, and have ample clearance excavated back of the ditches to provide room for pushing snow. Road sections of this type would naturally have a higher first cost, which could be considered as insurance against future damage from frost.

THE NORWEGIAN STATE RAILWAYS' MEASURES AGAINST FROST HEAVING

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Frost heaving is a serious economic and technical problem for Norwegian roads and railways, due to severe winter cold and the extensive occurrence of fine-grained sediments and moraine deposits.

A section through frozen and strongly frost-heaving soil reveals a series of isolated and nearly horizontal ice layers that can vary in thickness from 1 to 100 mm. These ice layers are often limited in horizontal extent and are thickest through the middle section. A local accumulation of a number of such lens-shaped layers often manifests itself at the surface by marked and sharply defined "frost humps."

The formation of the ice layers is due to special physical conditions during the process of freezing, which only in recent years have been made clear. The water is furnished by capillary action in the underlying unfrozen soil, and this movement is initiated by forces of diffusion through films of water at the lower limit of the frost zone. If this limit remains unchanged for a period of time and the temperature is sufficiently low, the thickness of the ice will increase. It is the resultant surplus of water that gives the ground a nearly fluid consistency after the spring thaw.

The Norwegian State Railways was forced at an early stage to take up the battle against the evils of frost, and the following account will set forth the methods chosen to combat them.

One measure that to a certain extent reduces the harmful action of frost is the laying of an 0. 5 m. thick ballast (gravel or broken stone) on a well-drained roadbed. And where the roadbed is of such a consistency that it becomes saturated in the spring thaws and thus loses its carrying capacity, reinforcements have usually been effected by the laying of stone or gravel foundations. On the most difficult stretches, especially deep ditches or covered drains have been used. Even though the ballast under the ties still gets pressed down into the roadbed in spring on a few old sections, so that the soil works its way up between the ties (Fig. 1), such occurrences are rare enough to be