density and moisture content at the time of compaction, on the ability of our loessial materials to maintain their load-supporting characteristics through the freezing-andthawing period.

# REMEDIES AND TREATMENTS BY CONNECTICUT HIGHWAY DEPARTMENT 

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## Synopsis

Frost action is a major problem in Connecticut highway work due to the climate, widespread existence of silty or clayey glacial till, and frequent small areas of silt and clay glacial lake deposits.

The remedies and treatments used are adequate subbase and underdrains. The subbase is invariably clean bank-run gravel, found abundantly throughout the state. On new construction of primary roads, the combined thickness of pavement (surface and base) plus subbase in earth cuts is from 20 to 32 in. , which is $2 / 3$ or $3 / 4$ of frost penetration; the combined thickness is 32 in . in rock cuts and about 14 in . in earth fills. The last may be reduced to 8 in . if cuts exceed fills. On secondary roads these thicknesses are reduced slightly. On tertiary roads (town aid), these thicknesses of pavement plus subbase total 8 to 20 in ., depending on conditions. These thicknesses are influenced by soil types, the greater amounts being used in silts and clays and the lesser in tills. In clean sands and gravels, subbase is greatly reduced or eliminated.

On new construction an underdrain is placed in wet cuts to drain the subbase, intercept sidehill seepage, lower the water table, or do all three. The underdrain is located under the middle of the shoulder or under the gutter. Depth of underdrain depends on frost penetration, type of soil and thickness of pavement and subbase; usually it is 5 ft . below top of shoulder in earth cuts. In rock cuts, the underdrain is 4 ft . below top of shoulder, serving only to drain the subbase.

On existing roads, the usual practice is to install an underdrain where frost action has occurred. The underdrain is usually cheaper than removing the pavement and poor soil and then installing subbase and new pavement. Also the underdrain often is needed to drain the subbase and pavement and sometimes to carry surface water as well. The same design for the underdrain is used on an existing road as for a new road, except that where the existing road is deficient in subbase, the underdrain may be deeper. Subbase deficiency in old roads is a frequent condition, particularly under the shoulders. However, when the soil is practically pure silt or clay, pavement and shoulders are removed and subgrade excavated to almost full depth of frost and replaced with good gravel subbase and new pavement and shoulders.

The climate in Connecticut is fairly cold, producing depths of frost of about 24 in . in the southern half of the state and increasing to 36 in . at the northern border; in the western part of the state, frost is 6 to 12 in . deeper than the above figures because of the higher altitude. These figures are under surfaces kept free of a snow cover, such as ploughed highways. Precipitation is rather high, averaging about 45 in . per year, and is quite evenly distributed over the months. About 80 percent of the state's area (1) is covered with glacial till, composed of approximately 30 percent boulders, cobbles and gravel, 40 percent sand and 30 percent silt, with or without clay. These percentages may vary plus or minus 15 or 20 percent. These tills are very dense in the natural state, weighing from $1^{2} 25$ to 145 lb . per cu. ft., dry density. They are rather impervious. They heave appreciably but usually uniformly and hence their chief trouble is
from frost boils (spring breakup) in flexible pavements and some pumping action at joints and cracks of rigid pavements. Most of the remaining 20 percent of the state is covered with glacial lake deposits which occur in every valley in the state. As the highways often follow the valleys, their importance is greater in highway work than their comparatively small area would indicate. These glacial lake deposits produce excellent bank-run gravels and coarse sands which are excellent for highway work and also fine sands, silts and clays. The last two are bad in heaving and in breakup or pumping; frequently they occur as a small arm of a temporary glacial lake and hence the highway has an abrupt heave when it crosses such spots. The latter are sometimes known as silt or clay pockets. These short differential heaves are sometimes from 4


Figure 1. These cross-sections indicate how shoulder heaving was practically eliminated by excavating to a 30 -in. depth and filling with clean bank-run gravel in the preceding fall.
to 7 in . high and usually are a hazard to traffic. The silts heave 20 or 25 percent (i. e. , when the silt develops ice lenses, its thickness increases 20 or 25 percent). Clays heave slightly less, and tills heave about 10 percent.

An example of heaving in silt is shown in Figure 1. The highway, built in 1941 in a northern Connecticut town, passed over the west edge of an old glacial lake-bed on soil that for at least a depth of 12 ft . is a light-brown silt having a small amount of fine sand. The pavement was an $8-\mathrm{in}$. concrete slab on a $10-\mathrm{in}$. gravel base, but the shoulders consisted simply of 6 in . of gravel, surfaced with oil.

When the road was built, a $6-\mathrm{in}$. perforated-metal underdrain was laid under the west gutter near the foot of a hillside; the invert was placed 50 in . below the pavement. In prolonged wet weather there is a good discharge from the underdrain, since it intercepts seepage off the hillside; but in dry weather it is dry. Under the opposite or east shoulder, the ground-water table in summer was 9 ft . below the pavement; but early in the spring it was $6-1 / 2-\mathrm{ft}$. below the pavement. Frost penetrates to about 3 ft . below the pavement. In spite of the underdrain, heaving of both shoulders was severe. The rise of the shoulders prevented lateral runoff of surface water in the winter, resulting in an icy pavement. Figure 1 gives cross-sections at the worst heave area. Heaving averaged about 5 in . at the east shoulder, 4 in . at the west shoulder and 2 in . at the pavement.

Later the east shoulder was excavated to a $30-\mathrm{in}$. depth for one-half its length and
clean bank-run gravel placed, resulting in only about 1 in . of heaving where thus treated. Samples of frozen silt taken where the shoulders had not been excavated showed a water content about one-half more than the normal. This excess water was sucked up from below during the heaving process to form ice layers; its volume, plus the expansion of all the water when changing to ice, checked very well with the actual observed heaves where these samples were taken.

The object of the design and treatments is not to eliminate frost action, but to reduce it to a low amount so that damage and maintenance will be very small and load restrictions during the spring are not necessary.

The remedies and treatments used are adequate subbase and underdrains. On new construction the primary requirement is adequate subbase, as an additional amount cannot well be added after the pavement is placed. The subbase is invariably clean bank-run gravel; crushed stone with a sand filler is also included in the specifications but is never used because the gravel is abundant and probably will continue to be for a considerable time. The gravel specification is as follows:

| Sieve Size | 5 in. | $1 / 4 \mathrm{in}$. | No. 40 | No. 100 |
| :--- | :---: | :---: | :---: | :---: |
| Percent Passing | 100 | 30 to 65 | 5 to 30 | 0 to 10 |

The portion passing the No. 100 sieve shall not have sufficient plasticity to permit performing the plastic limit test, AASHO, Number T-90.

Frost action in such gravels appears to be negligible. Little difficulty has been experienced in obtaining gravel to meet this severe specification, except in a narrow area of about 200 sq . mi. around Hartford where the red gravels (of Triassic origin) have considerable clay. Specifications for subbase in use before 1942 were identical with AASHO, Specification No. M-147-49 for base course; some of the red gravels passed that specification and were used at that time and subsequently have given some trouble in slight heaving, breakup, pumping at joints, etc. but probably the chief reason for changing to the more severe specification is that the better gravels are abundant.

Gravel base course and gravel surface (wearing) course, each 4 in. thick and together constituting the pavement, have the same specification as for gravel subbase, except that 100 percent shall pass the 3-1/2-in. sieve.

The lack of silt or clay binder in these pavement courses may be questioned by highway engineers. Such binder appears unnecessary in Connecticut highways as the gravel has excellent gradation and thus can be densely compacted, to about 130 or 135 lb. per cu . ft. and also the surface is bound by oil, tar or asphalt. On the minor town roads which are engineered, built and maintained by the towns, some are dirt roads and their surfaces probably include a silt or clay binder.

On new construction of primary roads such as parkway, federal aid, and trunk line, the combined thickness of pavement (surface and base) plus subbase in earth cuts is from 20 to 32 in , which is $2 / 3$ or $3 / 4$ of frost penetration; the combined thickness is 32 in . in rock cuts and about 14 in . in earth fills. The last may be reduced to 8 in . if cuts exceed fills. On secondary roads these thicknesses are reduced slightly. On tertiary roads (town aid), these thicknesses of pavement plus subbase total 8 in . to 20 in., depending on conditions. In low fills over wet ground, subbase requirements are the same as for earth cuts. The reason for the latter is that the water table is as close to the roadway surface (say 5 ft .) at the low wet fill as it is in a wet cut with underdrainage. Therefore unless such a fill is composed of clean material throughout its height, conditions for frost action are about the same in both cases and subbase requirements are the same.

Depth of subbase also is influenced by soil types, the greater depths given above being used in silts and often in clays and the lesser depths in tills. In clean sands and gravels, subbase is reduced to 6 in. or zero.

Subbase is carried out to the gutter on each side in cuts and to full width of shoulders in fills. Also the thickness in cuts is carried without diminution into fills for a minimum distance of 50 ft . before tapering down to the normal thickness in the fills. In the past this was not done, which resulted in bad heaves in the topsoil at the grade points.

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Figure 2. Method of Bliminating Serious Differential Frost Heaving Due to Chimney Action in Culvert.

The underdrain is located under the middle of the shoulder or under the gutter. Depth of underdrain depends on frost penetration, type of soil and thickness of pavement and subbase; usually it is 5 ft . below top of shoulder in earth cuts. If the subbase extended to full depth of frost, the underdrain could be shallower, serving only to drain the subbase, but this would increase the cost of construction materially. In rock cuts, the underdrain is 4 ft . below top of shoulder, serving only to drain the subbase. Six-in. pipe is used, usually perforated, asphalt-coated metal pipe, except that larger pipe is used if it is to carry surface water also. Perforations are usually on the top side of pipe, but if the water table is about level, they are on the bottom side; the recently-approved design with perforations below middle of pipe is now being used. Backfill is $1 / 2-\mathrm{in}$. stone, except that where the soil is fine-grained with no coarse fraction, washed concrete sand is used. The choice is usually determined by the piping ratio of backfill to soil (3).

On existing roads, the usual practice is to install an underdrain where frost action has occurred. The underdrain is usually cheaper than removing the pavement and poor soil and then installing subbase and new pavement. Also the underdrain often is needed to drain the subbase and pavement and sometimes to carry surface water as well. Another benefit is to lower the water table at the adjacent slope and thereby stop seepage onto the gutter and shoulder which is an ice hazard in winter. The same design for the underdrain is used on an existing road as for a new road, except that where the existing road is deficient in subbase, the underdrain may be deeper. Subbase deficiency in old roads is a frequent condition, particularly under the shoulders. However, when the soil is practically pure silt or clay, the pavement and shoulders are removed and subgrade excavated to almost full depth of frost, and replaced with good gravel subbase and a new pavement and shoulders.

A special case of frost action under pavements is due to chimney action in culverts, especially in cross culverts of large-diameter pipe. Cold air circulates through culverts, unless blocked with snow or water, and causes frost penetration into the earth outside the pipe. This frost penetration will result in vertical and horizontal heaving if the earth is a frost-heaving type and sufficient moisture is available.

An example of harmful chimney action is in a central Connecticut city where a duallane expressway crosses a wet area for about one mile. The 9 in . concrete pavement and 12 in . gravel subbase are on a low fill of alluvial silt; top of pavement is 4 to 7 ft . above ground. The ground is swampy, with water table at or near the ground surface. Elevations taken on 100 points on the pavement revealed that the ordinary heave here was $1 / 2-\mathrm{in}$. to $1-1 / 2-\mathrm{in}$., but at the four 36 and 48 in . cross culverts, heaves were 1 or $1-1 / 2-\mathrm{in}$. greater. The pavement was not reinforced, because of the steel shortage, and large transverse cracks developed at and near these culverts because of the nonuniform heaving. At the numerous 12 in . cross culverts, extending only one-half the width of the expressway, heaves were about $1 / 2-\mathrm{in}$. greater than normal and cracks developed over and near them also.

A good remedy for chimney action is the placing of non-frost-heaving fill around the pipe for a thickness equal to the frost penetration around the pipe. Above this fill would be the normal embankment material. If this amount is difficult to determine, an easier method is to fill with the good material up to subgrade and for some distance each side of the culvert, as in Figure 2. . If the culvert is far below the pavement, this method would be expensive. In such cases, no remedy would be necessary, except in unusual cases, as the heaving around the pipe would be diffused over a wide area by upward arching in the embankment and largely absorbed by compressive strains in the embankment.

A working rule in Connecticut is to use one of the above treatments if the embankment will be a bad frost-heaving soil and if top of pipe will be less than 4 or 5 ft . below top of
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

