year, so when money is available for reconstruction or betterment, plans may be based on a fairly comprehensive service record. At this stage a report is submitted with the map by the district soil engineer. In this report he makes design recommendations for correcting inadequate foundations. Included also is information on the location and character of needed construction materials available in the neighborhood. Figure 7 is a typical sample of condition map. The spring breakup records over a 3-year period are shown. In making his soil survey and in generally gathering data on which to base his report and recommendations, the soil engineer works closely with highway staff members concerned with the project. This is done so he may profit by their knowledge of the project and they may know more intimately some of the background for the report. A more sympathetic execution of the recommendations is thus assured.

REMEDIES AND TREATMENTS FOR THE FROST PROBLEM IN NEBRASKA

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The damaging effects resulting from the freezing and thawing of base and subbase courses and subgrades on Nebraska's highways can be classified under two principal headings: (1) local frost heaves and (2) widespread reduction in ability to carry loads, causing permanent deformation or actual breakup. The first of these occurs quite frequently, yet over the state as a whole it would be considered a minor problem. On the other hand, the so-called spring breakup frequently becomes a very serious matter, the extent of the problem sometimes becoming so great that special load restrictions are set for the spring months.

Frost heave is limited in extent, observable heaves usually measuring not longer than 40 or 50 ft., nor higher than 4 or 5 in. above the normal elevation. Usually the location of the heave can be correlated with the soil profile, and the relative permeabilities of materials in the different horizons is the most important single factor. The following table indicates the wide diversity of materials in which frost heave may occur if the soil layer in question is underlain with a more impervious horizon.

TABLE 1
SITUATIONS SUBJECT TO FROST HEAVE

	Example 1		Example 2		Example 3	
	Upper Stratum (Top-Soil)	Lower Stratum (Pierre Shale)	Upper Stratum (Fine Sand)	Lower Stratum (Pierre Shale)	Upper Stratum (Peorian Loess)	Lower Stratum (Glacial Till)
Liquid Limit	45	60	-	60	35	45
Plasticity Index	20	30	-	30	15	20
Percent Sand	15	15	98	15	15	20
Percent Silt	55	45	1	45	65	55
Percent Clay	30	40	1	40	20	25
Percent Passing No. 40	100	100	70	100	100	100
Percent Passing No. 200	90	90	5	90	98	90

It has been observed that situations such as those shown in Table 1 result in accumulations of excess moisture in the upper layer. The source of the water is usually from the precipitation on the adjacent shoulders, side slopes, ditches, and backslopes, though in some cases the seepage moves underground from considerable distances. This latter situation is illustrated in Example 2, which represents a region where fine sands overlie the impervious Pierre Shale over large areas. In these areas, free water fills all of the pore space in the lower 2 to 7 ft. of fine sand immediately over the shale and if the subgrade of a highway is constructed at an elevation within about 3 ft. of this water table, frost heave is the inevitable result.

In other cases, such as in Example 3, the rate of downward percolation of surface moisture through the Peorian Loess is greater than that through the more clayey till, and under these circumstances frost heaves often occur even though free water is not found at the loess-till contact. In most cases, however, an excess of moisture is found in the lower foot of the loess and these moisture contents are often greater than the liquid limit.

The frost heaves discussed above present dangers to the traveling public in the form of rough riding surfaces during the frozen period, but probably the most detrimental result arising from these circumstances is the extreme softening of the more silty or clayey subgrades during and for an extended time after the thawing period. The decrease in ability of the subgrade to adequately support base courses results in bituminous pavement breakup and severe cracking and settlements in concrete pavements.

The other problem, the general softening of subgrades and base courses during and after the spring thaw, not, however, accompanied by differential heave during the frozen period, is of vastly greater consequence in Nebraska when measured in terms of dollars required to prevent failure or to make repairs subsequent to failure. It has been observed that generalized excessive softening may sometimes be due to circumstances of the soil profile as indicated above to be related to frost heave but that more often the soil profile is not the significant factor. This line of thinking is supported by the observation that general softening occurs probably as frequently on fills as in cut sections.

Though the mechanics of softening of subgrades and base courses by frost action is still a subject of much discussion and divergence of opinion, it would appear that increases in the moisture content of the subgrade soil is one important factor. The data of Table 2 support this statement.

Table 2
AVERAGE MOISTURE CONTENTS

Depth Sampled	Project A* Condition Failure	Project A* Condition Good	Project B** Condition Failure	Project B** Condition Good
	Percent		Percent	
Base Course	4.6	3.8	5.1	4.3
1 in. below	18.5	17.2	19.0	17.0
6 in. below	18.8	15.9	19.8	18.0
36 in. below	19.7	17.3	20.4	17.5

* 10 borings in failed areas, 7 borings in good sections
** 27 borings in failed areas,17 borings in good sections

The tests represented in the table above were made during the spring breakup and the term failure includes a range of conditions from slight cracking to badly deformed and cracked pavement.

While the differences between average moisture contents in failing and good sections are not great, it is possible that those of the failed sections are slightly above, and those of the good sections are slightly below some critical moisture content beyond which increasingly greater deformations occur for any given load.

The data collected in the field for Project B included rather detailed descriptions of the various failures and a further breakdown of these data is shown in Table 3 on the following page. The grouping in this table representing two very distinctly different conditions, was made to determine if the higher moisture contents in the failed sections of Project B actually existed before the failures occurred or if they resulted from the

TABLE 3
AVERAGE MOISTURE CONTENTS

Project B.

Depth Sampled	Condition: Slight Surface Cracking* Incipient Failure Percent	Badly Cracked and Deformed** Plastic Flow in Subgrade Percent
Base Course	4.9	5.5
1 in. below	19.5	17.6
6 in. below	19.4	19.7
36 in. below	18.7	22.7

*Averages of 11 of the 27 borings in failures of Project B.
**Averages of 7 of the 27 borings in failures of Project B.

percolation of surface water through the failing surface. It is believed that practically no surface water had penetrated the surface course in the cases of incipient failure but that ample opportunity had existed for such entry in the cases represented by the right-hand column. It will be noted that the moisture contents in the cases of the incipient failures were already higher than those of the unfailed sections of Table 2, and that in general the moisture contents continued to increase after failure had progressed to an extent which permitted the entry of surface water. In this connection, it should be pointed out that the project was used as a gravelled road for a time previous to the construction of the pavement, and that considerable sand gravel had been incorporated into the first 1 in. of soil below the base course. This sand-gravel content was quite variable and therefore the moisture contents shown for this depth are not the true moisture contents of the soil mortar. This is believed to account for the apparently low (17.6 percent) moisture content at a depth of 1 in. below the base course in the right-hand column of Table 3.

As the samples of subgrade soil were taken during the investigation of Project B, they were tested to determine if their respective moisture contents were above or below a plastic limit defined as the minimum moisture content at which a 1/2-in. cube can be molded without cracking. In other words, an attempt was made in each case to mold such a cube and the degree of success was reported for each specimen. Table 4 reports the results of these tests.

TABLE 4
PERCENTAGE OF SOIL SAMPLES SUFFICIENTLY WET TO PERMIT THE MOLDING OF A 1/2-IN. CUBE WITHOUT CRACKING

Project B.

Depth Below Base Course in.	Condition: Failures Percent	Good Sections Percent
1	96	41
6	56	35
36	41	18

It is apparent that the actual moisture content of the soil mortar in the first inch below the base course was higher than would be indicated by the data of Tables 2 and 3.

Figure 1 shows data collected during the investigation of spring failures on Project C. The grading work on this project was completed in early fall of 1939, temporary gravel surfacing was placed and the road was used during the winter of 1939-40. During the months of June, July and August, 1940, a granular base course and a thin bituminous surface course were constructed.

It will be noted on Figure 1 that considerable increases in moisture content and apparently some increases in density have occurred during the 11-year interval. It is not known when these changes took place, though it is suspected that the highest moisture contents exist during the spring thaw, since this is the time of most frequent occurrence of failure.

It will also be noted on Figure 1 that the degree of saturation during the spring of 1950 was almost 100 percent in many cases.

Perhaps the most consistent observation we have made with respect to softening of subgrade by frost action is that this phenomenon can and does occur in any soil ranging from silty sands, through silty loams and including plastic clays, but that little trouble of this sort is experienced in the large sand-hill area of Nebraska, if the bituminous pavement is constructed directly on the clean sands (less than 10 percent passing the No. 200 sieve). Softening does occur in subgrades supporting bituminous pavements in the sand-hill area if a layer of silty sand or finer soil is placed between the bituminous pavement and the sand subgrade. Those of us who must consider the problems of base materials and thicknesses fervently hope that nature will some day reveal to us in some manner the depths of granular base courses required to support bituminous pavements over plastic soils as accurately as she has indicated the type of material required.

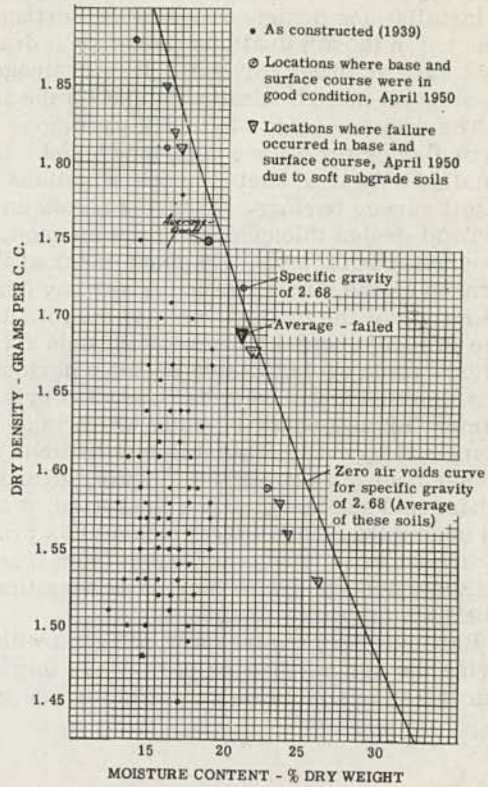

Figure 1. Project C - Subgrade Densities and Moisture Content.

Design Practices

Design to alleviate the effects of frost action in Nebraska may be discussed under the following: (1) surface drainage, (2) subsurface drainage (3) base and subbase course thickness, and (4) base and subbase course mixtures.

The adequacy of surface drainage from shoulders, ditches, and slopes of highways has in some situations a profound effect on the degree of distress caused by freezing of bases, subbases, and subgrades. It was observed on one project that failure occurred in some sections having sand subgrades while base and surface courses in good condition were noted on some adjacent or nearby sections where the subgrade soil was the A-7-6(20) Pierre Shale. In this particular case, the reversal from the general trend was attributed to differences in surface drainage, the ditches in the section of sandy subgrade having been filled with a clayey mixture eroded from higher ground to the extent that water was being ponded in the ditches. In a few cases in Nebraska, geometric designs have provided for deeper and wider ditches than normal in order to insure adequate surface drainage.

Embankments in sections of highways crossing old lake bottoms, or valleys where permanent water tables are near the surface, are generally constructed to elevations at least 7 ft. above the highest expected water table. Prevailing opinion seems to indicate that this requirement could be increased somewhat and the resulting decreases in maintenance costs would assure the economy of the change.

Installations designed to provide surface outlets for underground waters are constructed in those situations where such drainage is possible. At least two conditions must exist in order for subsurface drainage systems to function: (1) the water-bearing stratum must be drainable and (2) the topography must provide sufficient slope.

The decision as to whether a particular soil is drainable is often difficult and no particular criteria have been developed. In actual practice, subdrains are now being installed only in upland or slope situations where free water is observed in the bottoms of soil survey borings. Figure 2 shows an example of a design of such an installation.

Total design thicknesses of the surface, base, and subbase courses in Nebraska are based on four factors: (1) group index of the subgrade soil, (2) density of traffic expressed as the number of axles per day heavier than 5 tons, (3) mean annual rainfall in the region of the project, and (4) the situation (topography, height of water table, surface drainage, etc.). These standards reflect opinions and judgments based on observations made during spring breakup periods, when the bulk of our failures appear.

A detailed soil survey is conducted prior to preparation of grading plans for any primary or secondary highway which is to receive a paved surface in the foreseeable future. If potential frost-heave situations show up on the soil profile, extra thickness of base course is specified. Again, after grading is completed and before construction of base and surface courses is started, a subgrade survey is made, preferably during the spring thaw, and extra thickness is provided for sections shown by this survey to be subject to excessive softening from frost action. Consideration is now being given to experimentation with increased densities in the upper more pervious layer as a substitute for extra thickness.

Base course mixtures are designed with a view towards providing sufficient stability during the spring-thawing period. In this connection, it should be pointed out that the aggregates available in Nebraska for use in base-course construction are almost wholly

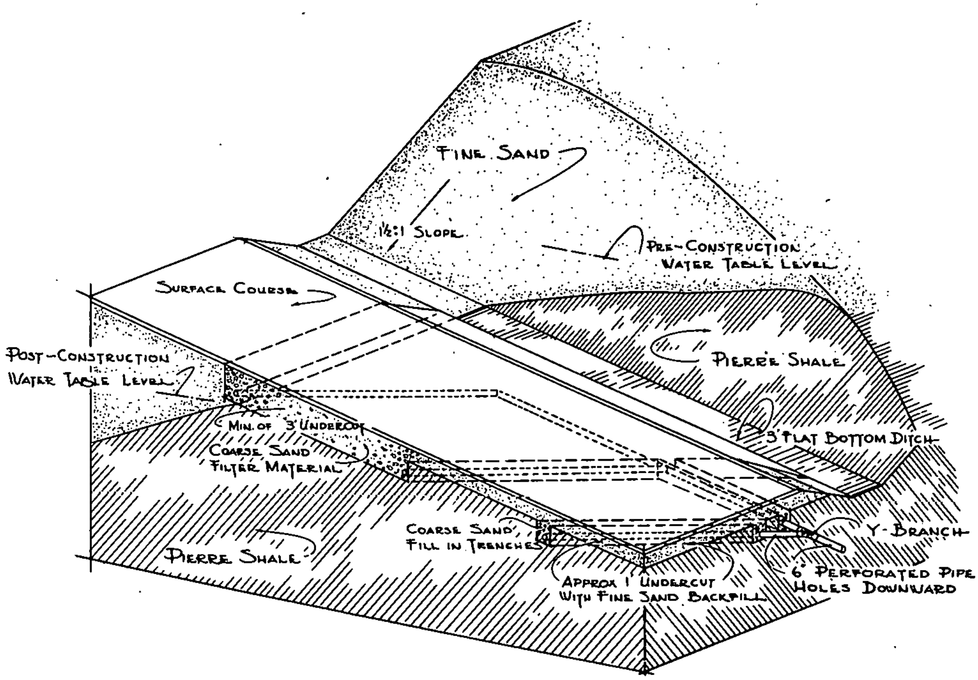

Figure 2. Pictorial View of Section Taken at Centerline Showing Left Half of Roadway.

the rounded waterworn sands and gravels which were rolled from the Rocky Mountains at the bottoms of Tertiary and Pleistocene channels. Some coarse sands found in the Nebraskan and Kansan Till sheets are slightly more angular in shape. All of these materials are relatively fine in texture, having maximum fineness moduli of about 5. With such aggregates, particular attention must be given to gradation. The trend through the years in design has been towards less binder, until the concensus now is that these base courses should be laid with the minimum clay content necessary for stability during construction. The following table indicates the typical test characteristics of granular mixtures now considered to be stable during and after the thawing period, and at the same time having sufficient cohesion that surface course mixing and laydown operations can proceed on the compacted base course.

TABLE 5
TYPICAL BASE MIXTURES

PI	Sand Percent	Silt Percent	Clay Percent	Percent Passing Sieve Number 4	10	20	40	100	200
2	94	4	2	75	50	35	25	12	9

Three different admixtures have been used in granular base courses in Nebraska in attempting to provide sufficient load-carrying capacity through the thawing period. These are asphaltic oils, portland cement, and calcium chloride. Sufficient success has been had with the first of these that its use has become commonplace. It should be pointed out that more minus-200 material (15-20 percent) is added to these base-course mixtures.

Granular base courses for concrete pavements are constructed in Nebraska in all cases where the percentage of minus-200 material in the subgrade soil is greater than 35 or the plasticity index is higher than 6.

The following principal reasons for constructing base courses for concrete pavements have been advanced: (1) to prevent pumping, (2) to prevent cracking of the pavement, and (3) to prevent heave or settlement at the joints.

Pumping at the joints probably is prevented to some degree by the base courses constructed in Nebraska, since they generally are of freely draining materials such as fine or coarse sands and the base courses are either constructed to extend from shoulder slope to shoulder slope or are provided with French drains.

It is believed that the greatest benefit derived from providing base courses for concrete pavements in this state is in the prevention of heave or settlement at the joints. Some of the loessial soils have the property of absorbing water quite readily and yet contain enough clay to result in considerable swell upon wetting. As a result, joint heave sometimes occurs during extended rainy seasons and, less often, during the period of below-freezing temperature. The sandy base courses, by providing a more uniform distribution of leakage water to the subgrade soil, tend to prevent the differential swelling in the summertime and joint heave when the ground is frozen.

Remedial Measures

Returns from a recent questionnaire directed to supervisors of maintenance crews reflect a line of thinking very similar to that of the Design Division with respect to the requirements of a highway subgrade and pavement structure if it is to be free of the damaging effects of frost action. It is almost universally agreed that a freely draining granular base course of sufficient thickness will eliminate troubles due to frost action, provided, of course, the surface course is adequate to perform its functions.

Two principal methods of repair of failures in bituminous pavements due to frost action are employed by the maintenance forces. The method used hinges on the circumstances surrounding the failure.

One method consists of the removal of a depth of the offending subgrade material and the replacement of this material with soil of better quality, base course mixture (granular), or bitumenized patching material. This method is used in those cases where it is determined that a relatively thin stratum of unsatisfactory soil occurs immediately below the base course and that its removal would solve the problem. The most frequently encountered situations of this type are found on the older roads in the sand-hill area, in cases where the upper 6 in. or so of the original subgrade had been constructed of clay or binder soil for the purpose of providing temporary wearing surfaces. To repair such failures, the clay layer is removed and wasted, fine sand is backfilled in this space, and the bituminous pavement is replaced.

The method of undercutting and wasting poor subgrade material is also employed in certain instances where deep strata of poor subgrade material cause failures for short distances. Cretaceous shales of the Pierre, Niobrara, Carlyle, Granerous, and Dakota formations are sometimes encountered in excavations of the eastern half of the state. Usually Pleistocene deposits overlie those of Cretaceous age. If these projects were graded today, the shales would be undercut and replaced with granular materials of the younger formations. But this was not done on the older projects, and as a result the maintenance forces sometimes find it necessary to perform this operation to avoid being confronted with repeated failures in the same locations after each spring thaw.

The other principal method of repair of bituminous pavements after failure due to frost action is to increase the total thickness of base and surface courses. In many cases, where slight cracking and deformation have occurred during and after the spring thaw, the failures have tendencies to heal themselves during the following summer. Some have found that such sections need only small increases in thickness and resealing to be permanently repaired. In many cases additional bituminous mix material laid only 1 or 2 in. thick resulted in a satisfactory surface for several additional years.

In those cases of serious and more complete failure of bituminous pavements, sufficient additional thickness of surface course sometimes cannot be applied over the old pavements without narrowing the riding surface more than is desirable, since a shoulder slope of about 3: 1 has to be maintained. The only satisfactory method of adding thickness in such situations is to remove the surface and base courses and a thickness of subgrade soil equal to the increase required. Old base material, new base material, and surface course are then placed. This of course then becomes the same as the first method above.

Materials used by maintenance forces in replacing subgrade soil found to be susceptible to effects of frost action vary from crushed rock through coarse sand to fine sand. Since crushed rock must, for the most part, be imported from the neighboring states, and since the cost of shipment becomes prohibitive for most of Nebraska, the bulk of materials used for such purposes are the corase sands and fine sands of Pleistocene age. These have been discussed previously in this report.

Little has been done by the maintenance forces to remedy frost heaves, since these constitute a minor problem. Intercepting drains have been tried in some cases, but these have not always proved to be effective, possibly in some cases due to improper installation. Crushed concrete and crushed rock have been used as filter materials in some of the drains and these probably have become plugged. Cases are noted where the flow immediately after installation was considerable, but discontinued after a year or two. Some of the drains probably are of insufficient depth, usually not over 3 or 4 ft. below the surface.

If the frost heave of the frozen period becomes a frost boil during and after the thawing period, then of course, repairs are made as outlined above. Some experimentation with calcium chloride as a preventative of failure due to frost action has been attempted by the maintenance forces, but reported results are inconclusive.

Two investigations are now under way at the testing laboratory of the Department of Roads and Irrigation in connection with the effects of frost action. The first is an attempt to adopt the triaxial test method to the design of base-course mixtures which will be free from the damaging effect of frost. The second concerns the effects of 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-and-thawing period.

REMEDIES AND TREATMENTS BY CONNECTICUT HIGHWAY DEPARTMENT

Philip Keene, Engineer of Soils and Foundations, Connecticut Highway Department

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 125 to 145 lb. per cu. ft., dry density. They are rather impervious. They heave appreciably but usually uniformly and hence their chief trouble is