PREVENTION OF DETRIMENTAL FROST HEAVE

By J. O. Morton, *Construction Engineer, N. H. State Highway Department,*
Bailey Tremper, *Materials Engineer, Washington State Highway Department,*
O. L. Stokstad, *Engineer of Soils, Michigan State Highway Department*
and Dr. Leo Casagrande, *General Inspector for German Highways*
Arranged by Edward A. Willis, *Associate Highway Engineer, U. S. Bureau of Public Roads*

The physical laws controlling the occurrence of frost heave in soils have been defined by the research work of Taber (1),[1] Mullis (2), Bouyoucos (3), Wintermyer (4), Burton (5), Benkelman (6), Olmstead (7), Casagrande (8), and others in this country, and by the notable contributions of Beskow (9), in Sweden.

Briefly, water freezes in certain soils in the form of layers or lenses which grow at the expense of unfrozen water supplied by gravity or capillarity from a free water source. Under prolonged freezing action, the growth of these layers, in the direction of greatest heat transfer, causes an upheaval of the surface which may amount to more than a foot. This movement, referred to subsequently as the frost heave, is often enough to disrupt road pavements. Where non-uniform heave occurs, it may produce surface irregularities which are distinct traffic hazards.

When the temperature rises above the freezing point, thawing starts at the surface and progresses downward. This action liberates the large quantity of water which has been accumulated in the form of ice layers. The still frozen undersoil prevents the water from escaping with the result that the soil immediately below the pavement temporarily provides low support. Unless the pavement possesses sufficient beam strength, failures in the form of breakage and displacement occur. This condition is known as the "frost boil" and is distinct from the frost heave as previously defined.

[1] Figures in parentheses refer to list of references at end.

Whether or not frost heave will occur depends upon the quantity of moisture capable of being raised to a given height above the water table in a given time. Neither the height to which water will rise by capillarity nor the rate of such rise is alone the determining factor. In order to furnish capillary moisture in deterimental amounts, the pore size must be small enough to supply appreciable capillary pressure, but large enough to prevent too much frictional resistance to flow. These conditions are usually met in very fine sands and silts, and as a result, the most pronounced heaves are encountered in these soils.

Morton: Graded soils, sometimes known as cemented soils, hard pans or glacial tills although not having the capillary powers of uniformly grained soils do possess the ability to produce ice layers. These materials are particularly dangerous in the presence of a high ground water table or in areas of side hill seepage. The silt and clay content of the soil, the depth of freezing, and the availability of water are direct functions of the amount of frost action they are capable of producing. Pavement heaving amounting to eight inches is not unusual over soils of this nature.

Fine sands may be productive of frost disturbances when encountered where an underlying impervious material cuts off downward movement of gravitational water. A supersaturated soil may result from intermittent freezing and thawing under these conditions. Results are often severe enough to destroy pavement surfaces.

Conditions are encountered where complete frost elimination is not justified when the economic value of the road is taken into consideration. When these conditions are present uniform frost heaving may be permitted.

PREVENTIVE MEASURES

Morton: Having the knowledge of what causes frost action, and given a method of determining these conditions, the question arises of when this information should be applied to highway work. To prevent deterimental frost heave successfully it is necessary: First, that accurate information be had about foundation conditions before the design of the road is made; second, that the design of the road inculcate the necessary features to correct foundation irregularities; third, that construction practices adhere to the essentials set forth in the design and act as a means of checking foundation conditions predicted or overlooked by the soil survey. In the construction period it is essential that careful foundation observations be made in order that conditions arising from construction methods may not injure phases of the design. During this period it is possible to apply corrective measures to foundation irregularities not anticipated in the original design. However, this practice is dangerous especially when major changes are necessary. Today, speed of construction appears to be a major prerequisite, and there is little time allowed to apply corrective measures unless these precautions are included in the original design.

A typical method of preventing detrimental frost heave is carried out in the New Hampshire highway organization by the following methods: Once the survey line has been established, a soil engineer assigned to the project makes a soil survey. Upon its completion the survey is turned over to the design engineer. This survey, in its completed form, recommends alignment changes to avoid detrimental foundation conditions and includes recommendations for establishing the finished grade of the road. Upon establishment of the finished grade it accurately locates the depth and extent of base course construction and the surface or underground drainage to exacting limits. In recommending alignment changes the soil survey plays an important part in the prevention of frost heave. Certainly to avoid dangerous foundation materials without injuring alignment features is good practice. By establishing a grade at the proper elevation it is often possible to build the road above the influence of detrimental foundation conditions. The soil survey has proved in many instances that balanced earth quantities are not economically sound. The extensive use of good local borrow materials in many cases enables the road to be built above the influence of poor subsoil conditions and at the same time reduces construction costs. With the finished grade established the soil survey pictures foundation conditions that influence construction and permits the design to incorporate features that will remove their dangers.

Experience has proved that the following preventive methods are successful in eliminating destructive action. The fine grained soils (silts and clays) when found adjacent to materials that do not produce frost action are capable of producing sharp differential frost heaves. Treatment of this condition consists of removing the silt or clay pocket to a depth that is below the frost penetration line and constructing a base course of non-frost heaving material. Because of their high capillary properties, underdrains constructed at standard depths have not been effective in reducing frost action and in some cases have even proved deterimental. When extensive areas of such material are encountered, complete elimination of frost action may not bé economically sound. Under these conditions uniform frost action is permitted and is attained through varying the depth of base course material.

Graded soils—hard pans, glacial till or cemented soils and fine sands are capable of building ice layers yet lack high capillary powers. Their frost action is dependent on the presence of available water and depth of freezing. Preventive methods consist in the extensive use of underdrains located to cut off side hill seepage or to lower existing ground water tables and the use of non-heaving base course material. Underdrains should be constructed at depths that effectively remove water from within the frost penetration line. The permeability of the soil has a direct effect on the value of underdrain construction and this factor regulates the amount of base course material required for frost heave elimination. As in the previous case, uniform frost heaving may be permitted and controlled by regulating the depth of base course construction.

In New Hampshire frost penetration amounts to about four feet in depth. This penetration occurs on roads where complete snow removal is a part of regular winter maintenance. Under these conditions typical measures used to prevent detrimental frost heave consist of:

(1) Construction of gravel bases 4 ft. deep through silt or clay deposits or the use of a gravel base course 18 in. deep through these areas where uniform frost heave is to be permitted.

(2) The construction of gravel bases 12 to 24 in. deep through graded soils.

(3) The construction of 6 to 12 in. gravel bases through cohesionless soils.

(4) Standard underdrain construction consists of using 6 in. perforated bituminous coated corrugated metal pipe constructed in the ditch or shoulder line to a depth of 4 to 5 ft. below the finished grade of the road.

(5) Fill sections less than 4 ft. above the original ground are treated as cut sections. On fill sections over 4 ft. deep base courses of gravel 6 to 12 in. in depth are constructed.

Tremper: The State of Washington may be divided into two zones which differ greatly in climate and soil. West of the Cascade Mountains rainfall is heavy, averaging about 50 in. annually. Winters are relatively mild with but infrequent periods of sub-freezing weather; the temperature seldom dropping below 10 degrees F. A wide variety of soils may be found in Western Washington. Glacial gravel deposits cover a large area in the northern part. Much of the remainder consists of silty clays, of the A-5 type. In Eastern Washington the annual precipitation ranges from 7 to 18 in. Winters are quite severe, subfreezing weather occurring over a period of several months with the temperature dropping occasionally to −20 to −25°F. Frost commonly penetrates to depths of 3 to 4 feet. Much of Eastern Washington has been covered with lava. Glacial gravels are found in the valleys to the north while plastic and nonplastic silts of the A-4 group lie above the lava in the central and southern portions.

Methods of prevention of detrimental frost heave used in Washington have, in general, been those dictated by considerations of economy. To remove silts from the subgrade down to the frost line and to backfill with less susceptible soils would be out of the question in many areas in Eastern Washington because of the widespread occurrence of the silts and the lack of suitable soils for replacement. The road builder has been fortunate in Washington in that deposits of gravel, talus and ledge rock are quite liberally distributed over the State. For this reason relatively thick blankets of granular material can be applied economically. Ballast courses of this sort are necessary for support in Western Washington because of high rainfall but they also serve the purpose of providing non-capillary material above the relatively shallow frost line. In Eastern Washington blankets of from 12 to 24 in. have been effective in spite of the fact that frost penetrates considerably deeper and that frost boils are of common occurrence in unballasted roads. That they have been successful may be attributed primarily to the fact that the soil is uniform over wide areas, giving little cause for differential heaving.

The use of granular blankets may be said to be the general method most in favor in Washington for treatment against detrimental frost heave. The method has been successful however only through proper design of the roadway section and careful control of the quality of material.

It was found early in the use of ballast courses that they must extend the full width of the roadway to the ditch line otherwise water would be trapped between impermeable shoulders and be a potent cause of unequal frost heave. It is important that the shoulders be sealed with fine material which is compacted thoroughly in order to prevent infiltration of foreign material.

Older work of the trench type has been reconstructed by excavating the shoulders and replacing with pervious material. In other cases French drains leading through the shoulders to the side ditch have been effective where the grade was not too flat.

Granular materials containing an insufficient amount of sand sizes were found to permit the penetration of subgrade soil into the interstices. Since the amount of soil entering the base varied greatly in short distances, abrupt changes in the amount of uplift due to frost occurred in the surface. It is now the practice to place a layer of sand or rock screenings on the subgrade to prevent infiltration into the overlying ballast.

Granular materials are effective against frost heave only insofar as they prevent the rapid movement of water into the zone of freezing. For stopping capillary rise from the water table they serve excellently. Other cases arise, however, in which water may enter the open textured base in quantities sufficient to permit frost heave. Failure to locate and drain springs and potential springs in the roadway is one source of trouble. Such water is collected in perforated pipe drains in gravel-backfilled trenches beneath the surfacing. Best results have been obtained by placing one drain parallel with the highway with lateral drains at an angle of approximately 35 deg. spaced so as to drain the entire area affected. In maintenance work, perforated pipes driven under pavements have been successful at times.

To prevent the accumulation of water on impermeable subgrades underneath the ballast, the surface is graded to a crown of $\frac{1}{4}$ in. per ft.

Side ditches must be kept open to prevent water flowing into the ballast. Severe frost heave has been noted where side ditches have been choked with snow particularly on superelevated curves and more frequently at elevations in mountain passes where daily freezing and thawing occurs. Wide shoulders to hold compacted snow removed from the pavement make it easier to keep ditches and cross-culverts open.

Depressions in solid rock cuts when not carefully drained individually have served as local reservoirs of water and unequal frost heave has resulted. Drains are difficult to locate and costly to construct in rock. Satisfactory results have been obtained at less expense by backfilling with well-grade granular material entirely.

Failure to exercise sufficient caution against local excesses of cohesive soil in ballast courses has permitted the accumulation of water beneath joints in concrete pavements and permeable areas in bituminous surfaces. Freezing has then resulted in temporary roughness at pavement joints if not breakage of the slabs. Both surface roughness and breakage has occurred in thin bituminous surfaces.

Subgrade treatment is not, in general, required on glacial sand and gravel. Failure to locate pockets of glacial flour in silt seizes, however, was responsible for the upheaval and cracking of a short section of newly-constructed concrete pavement that had not yet been opened to traffic. The affected area was on a flat grade in a cut. Heavy rains preceded a period of unusually low temperature. Although the pavement was heaved as much as $1\frac{1}{2}$ in. over a considerable distance, it was only in the area in which silt pockets were subsequently found that cracking of the slabs occurred. Since an adjacent strip of pavement in a four-lane roadway was yet to be constructed, the silt-bearing gravel was removed to a depth of 18 in., well below the frost line, and was replaced with silt-free material. The side on which the pavement had already been constructed could not be treated in this way. A more expensive method by installing a long pipe drain along the ditch line was used. Both pavements passed through the winter of 1937–1938 without further damage.

A concrete pavement two years old has remained substantially free from cracks except in the approach panels to a number of bridges. Damage to these slabs was the result of connecting them to the bridges by means of dowels. The pavement throughout its length raises from 1 to 2 in. each winter due to frost. Restraint to vertical movement at the bridge seats has produced sufficient bending movement in the approach slabs to cause cracking. In more recent designs, dowels have been omitted at bridge connections and means have been used to prevent the entrance of soil into the opening under the approach slab when it is not in contact with the bridge seat.

Stockstad: In Michigan conditions causing serious frost heaving are so easily recognized that, in most cases, a field examination without laboratory tests is all that is necessary to devise corrective measures. Laboratory samples are collected, however, in order that there may be a complete record on file of the nature of the material treated. A bank of test results on materials recognized in the field as being destructive subgrade soil textures may also thus be built up.

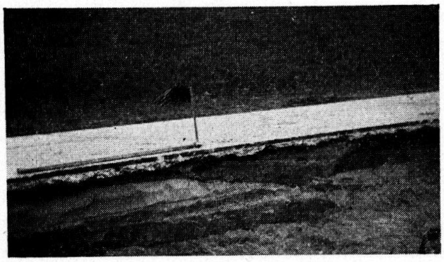

Figure 1. Old Frost Heave Being Excavated $\frac{1}{2}$ Roadway Width. The picture is a profile view at centerline of the stratified silt, very fine sand, and sand subgrade. Michigan.

In the prevention of detrimental frost heaving, the soil classification survey which is made for preliminary and final design purposes provides information in a general way as to the extent and location of conditions likely to cause frost disturbances. From this survey the kind of treatment and the approximate quantities involved are prepared by the Design Division. The definite location and analysis of the problems are accomplished after grading operations are under way and the cuts opened. Destructive soil textures are identified while the contractor has his equipment handy so that excavation does not necessitate moving heavy equipment back and forth on the project more than is absolutely necessary. Careful studies are made of soil drainage conditions so that artificial drainage structures may be adequate without being over-designed. Careful examination of the grade as grading activities progress seems to be the most efficient method of correcting faulty subgrade conditions especially in heavy grading areas characterized by sudden and extreme changes in soil textures and drainage conditions.

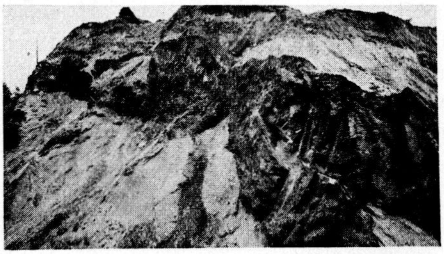

Figure 2. Sudden Changes in Soil Texture Exposed in Cuts through Morainic Areas. Such variations in texture favor differential heaving which in turn is responsible for rough riding and broken pavement. Michigan.

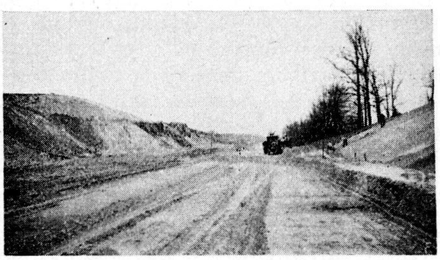

Figure 3. Materials for Backfilling Frost Heave Excavations May Be Found in the Same Cut. Note the unfinished bank of sand left for later use as subgrade material. Michigan.

When intermittent pockets of silt and very fine sand are encountered in a single cut, and the soil materials surrounding the frost heaving textures are sandy, the entire cut may be mixed, preferably with scrapers of the Le Tourneau type. This treatment results in a very uniform textured subgrade with the silt and very fine sand so evenly distributed throughout the sand that grading of the subgrade soil may be actually improved.

Simple excavation is by far the most common method of treating frost heaving materials. If the soils surrounding the excavation are of an impervious nature any porous backfill used must be drained artifically. In addition, the resulting subgrade lacks uniformity. The present tendency, therefore, consists of backfilling the excavation with material similar to the adjacent soils and then placing a 12 inch sand subbase over the entire subgrade area of clayey soils. Frost heaving materials are excavated or manipulated 4 ft. wider than the proposed road metal and to depths of from $2\frac{1}{2}$ to 4 ft., the greater depth being used only in particularly bad areas of northern Michigan.

Figure 4. Drainage Conditions Encountered in a Sand Cut as the Excavation Approaches a Deep Substratum of Impervious Clay. This condition was corrected by means of open joint sewer and tile under drain. Michigan.

The elimination of bad drainage conditions is accomplished by proper elevation of the grade whenever possible, but occasionally so called perched water tables are encountered in cut sections within 5 ft. of the highway surface. The most common treatment of this problem consists in placing a tile edge drain 5 ft. deep from 2 to 4 ft. from the edge of the metal on the side from which the water is moving. It is important that at least a 12-in. outfall be provided at the edge drain outlet in order to avoid excessive maintenance at this important point. Roadside ditches are generally considered inadequate for subgrade drainage except when constructed as drains of depths equaling 6 ft. or more. Inasmuch as roadside ditches of such depths are dangerous, the present trend is definitely toward covered roadside drainage systems.

It was formerly thought that if the subgrade was of uniform texture, such heaving as might occur would be uniform.

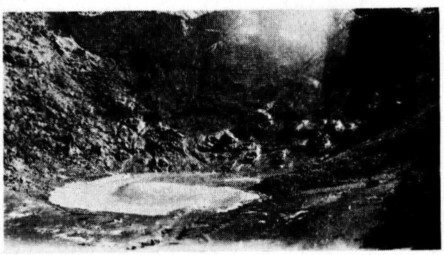

Figure 5. Excavating through a Deposit of Frost Heaving Material. This cut was excavated 3 feet below grade and backfilled to grade with sand. Michigan.

Experience indicates, however, that this is not the case, and that even in uniform soils there may be sufficient variation in moisture content or other factors to result in some differential heaving. It has been found that the consequent roughening of the road surface on plastic soils can be effectively eliminated by the use of a 12-in. sand subbase. In Michigan, therefore, where sand is almost always available within reasonable haul, the practice of using sand ballast below the road metal over all cohesive soils has recently been established. This treatment is especially effective when used in connection with flexible road surfaces.

Unexpected heaves which sometimes occur may be due to a number of factors. Figure 1 illustrates a case where, in the construction of an embankment, two widely varying fill materials were not tapered at the balance point. This example emphasizes the necessity for the soils engineer to be constantly on the alert in order to recognize not only soil conditions but construction practices which may become the cause of serious differential winter heaving.

Another common source of heaves is the presence of small culverts at shallow depths. It has been found that the minimum cover (usuallly 12 in.) required over culverts varies with the soils encountered, well drained sands and gravels requiring less cover than finer textured soils. Certain loamy soils in northern Michigan are particularly susceptible to culvert heaving especially in districts where steam jets are used to thaw the ice out of drainage structures in the early spring. The culvert becomes permanently raised below the road surface leaving each end of the pipe in its original position. The resulting heave is usually more serious during the summer season than at any other time. It may be possible that the steam jets cause melting around the culvert enough to encourage infiltration of fluid subgrade material into a cavity below the heaved structure thus preventing it from settling back into place after the frost has left

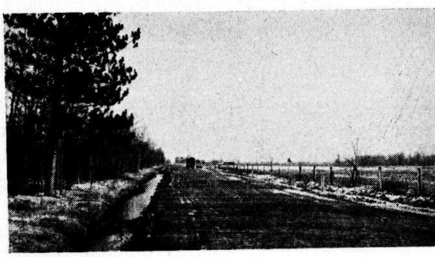

Figure 6. Continuous Spring Blading Will Enable a Gravel Surface to Carry Light Traffic Even with Drainage Conditions as Illustrated. A higher grade line, however, will be the eventual solution to this problem. Michigan.

the ground. The accepted solution for this problem consists in using selected fill materials in the approaches to the culvert, or building a grade sufficiently high to provide approximately 3 ft. of cover over the culvert pipes.

The concentration of water as ice in the upper 2 to 6 ft. of all fine grained soils causes some heaving, the extent or differential of which may or may not seriously affect traffic or the highway surface. The release of this frozen water during spring thaws together with spring rains is responsible for the spring break-up, the most serious problem

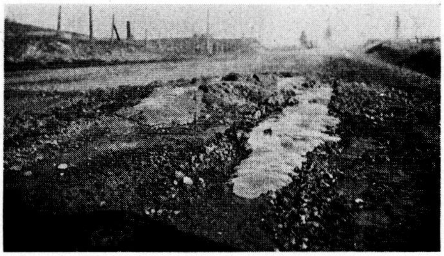

Figure 7. A Frost Boil Rupturing near the Edge of the Metal Permitting Escape of a Fluid Subgrade. Deep frost prevents a downward movement of water. Michigan.

confronting highway engineers interested in the construction and maintenance of low cost roads. Roads of this type depend on the stability of the subgrade for their ability to carry traffic. Road metals like portland cement concrete have the capacity to cover up subgrade sins or deficiencies for many years, but all low cost surfaces are very sensitive to deficiencies in subgrade support. The uniformity of this support during the four seasons cannot be over emphasized, and it is in this respect that the usual soil tests, by their improper use, fail as a means for supplying design information. Test results obtained in August, for instance, would be totally different from the results of tests made in April. In other words, subgrade stability tests are only of value when considered in conjunction with the great seasonal variations in subgrade moisture contents.

The old-fashioned gravel roads have a distinct advantage over other low-cost types during spring break-up periods in that they can be maintained by scrapers so as to keep them passable during the drying out period. An impervious cover over the gravel not only prohibits the use

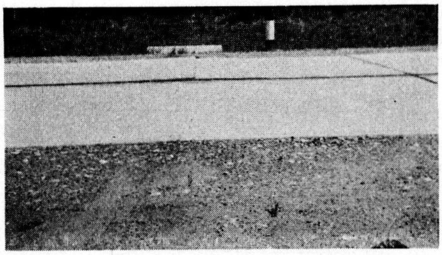

Figure 8. The Cracked Pavement Shows the Location of a Bad Culvert Heave. This type of heave is the result of winter freezing even though it is most apparent during the summer season. Michigan.

Figure 9. Snow Banks over Shoulders and Ditches Prevent Frost Penetration, and at the Same Time, Supply Capillary Moisture for the Freezing Subgrade. Michigan.

of maintainers but also considerably lengthens the period necessary for the subgrade to properly dry out. Bituminous treated gravel roads, therefore, often fail badly where the old untreated gravel served without serious difficulties.

Casagrande: One of the first rules of road building to-day is still to drain the road bed thoroughly. Drainage, without doubt, would help to prevent a good deal of surface damage, but the trouble is how to drain fine-grained soil. Almost without exception, fine-grained soil, the source of the trouble, cannot be drained, since the fine pores retain the moisture and besides this are able to accumulate moisture by capillary action. Therefore frost damage cannot be avoided by ditches. Even if the drainage should be excellent as, for example, on a higher fill, which corresponds also to a ditch of the same depth, we can get frost damage. cases it will be sufficient to use a sand layer of 15 in. to 20 in. Where for financial reasons a thinner layer is used, it should not be less than 10 in. to 12 in. and should be protected with a filter layer to prevent penetration of fine grain particles.

When no sand, gravel, or cinders are available, penetration of moisture to the frost zone can also be prevented by means of a sand filter or a water-tight bituminous blanket at freezing depth. The

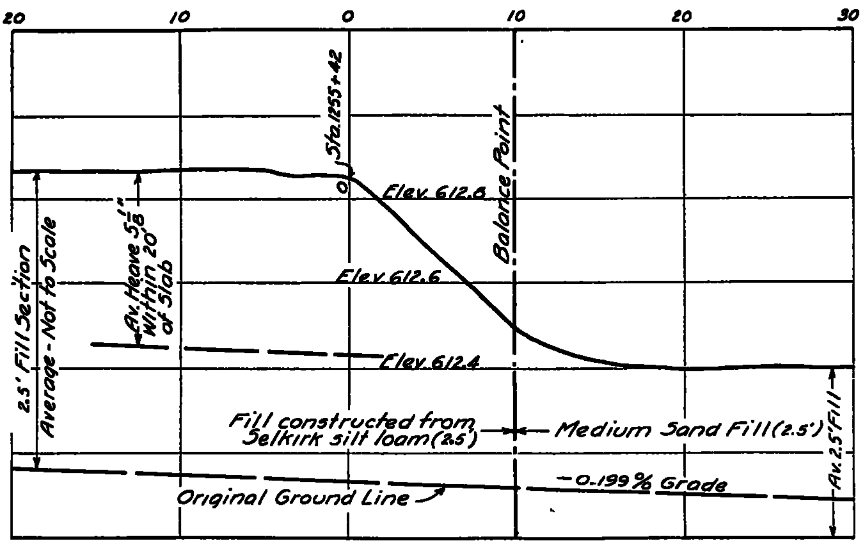

Figure 10. Profile of Differential Heave East of Isabella, Michigan, on Route U. S. 2

Experience has shown that fill material with a relatively high water content can lead to heavy frost action even many years after construction.

A great deal of investigation has been done and is still carried out to find efficient methods of frost protection and protection against damage by moisture accumulation. In Germany to-day the most common treatment consists in putting a layer of pure sand or gravel or cinders under the pavement. This layer should reach to the average freezing depth, that means to a depth of between 25 in. and 40 in. (in Germany). In most practical application of this latter method needs great care and should be done by experienced workers only, otherwise the first described method of protection should be preferred.

SUGGESTIONS FOR NEW RESEARCH

Stockstad: Laboratory research in connection with frost heaving has been going on for the last twelve years with the result that a large amount of information on the subject has been accumulated. Future research should therefore include more field investigations in order to study further the operation of fundamental principles learned in the laboratory. The following outline is submitted as suggestive of subjects for possible future field study:

I. A Study of the Frozen Subgrade Cross Section.
   1. To determine the position, arrangement and variations in ice formation.
   2. To study the manner of thawing.
      a. Is thawing below the centerline always more rapid than below the edges of the roadway?
   3. To gain more information with respect to changes in subsoil moisture content as a result of frost.
   4. To study the influence of snow banks on shoulders and in roadside ditches on:
      a. The shape of the frozen section.
      b. The availability of moisture during frost penetration in the subgrade.
      c. The shape of the partially thawed section.

II. A Study of Subgrades during the Spring Break-up Season.
   1. Bearing value tests to determine:
      a. Variations in the bearing value of different soils.
      b. The critical bearing values to be used for design purposes.
      c. The thickness of sub-bases to be used and the suitability of various granular materials for this purpose.
   2. Moisture content.
      a. Influence of deep frost on the movement of gravitational water.
      b. Seasonal variation in moisture content.

III. A study to Associate the Results of Frost Heave Research with Soil Types.

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