jointly by the Indiana State Highway Commission and Purdue University. You may not know that this is unique, but it is—this rather simple matter of combining acute highway problems with the personnel, time, and facilities of a university. Of course, the research will not be limited to bituminous problems, but some of these offer a logical point of early attack because of the obvious interest Indiana has in this road type. It seems altogether likely that many valuable facts will be established and put at your disposal by this newly-formed Highway Research Project.

Russell Conwell gave his lecture "Acre of Diamonds" to hundreds of audiences who were thrilled by having the commonplace experiences, tasks, and opportunities glorified into something more than they seemed to be. I have risked copying his purpose. Hence, if this discussion has whetted your appetites for study and scientific observations of the bituminous mixes and roads of your daily experiences, then it has been more than a pleasure to appear before you today.

COMBATING FROST AND DRAINAGE PROBLEMS

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We have two distinct road problems which are connected with frost action. One is a heaving of the road surface during the winter, and the other is the softening of the supporting soil during what is commonly referred to as the spring break-up. The winters in Minnesota are as long as, if not longer and more severe than, they are in Indiana, and as a result, the frost penetrates to a greater depth. Minnesota has one advantage, however, and that is that during the winter the temperature does not vacillate around the freezing point as it does in Indiana. The road ordinarily freezes and stays frozen until spring, when the break-up occurs. The period of soft, muddy roads is probably shorter than it is in Indiana, but more severe while it lasts.

CONDITIONS ILLUSTRATED

This paper refers to Minnesota conditions, as the speaker is not familiar with the conditions in Indiana. When the conditions are such that a heave occurs, a badly cracked pavement results. It is rough and oftentimes dangerous for winter driving. The pavement never quite gets back to its original condition when the ice thaws, and it is therefore somewhat rough at best for summer driving. The slab becomes rougher with age, and eventually will crack into many small pieces, so that replacement is necessary.

Another road condition that is oftentimes accounted for by frost action in Minnesota is high joints in concrete pavements. In extreme cases, measurements have been taken where the joints were as much as two inches higher than the center of the slab between. These high joints, coming at regular intervals, give a sort of galloping motion to automobiles. We also have high joints which may be accounted for by the swelling of the soil, but this is another problem which does not particularly belong to the subject assigned for today.

In the spring when the frost leaves the ground, we have had some impassable places for short distances on otherwise good roads. Frequently these bad places were in cuts through hills. Figure 1 illustrates a thin, rubbery crust of dry material lying over saturated unstable soil. This dry crust may carry passenger cars, but is likely to break through under a truck. In the attempt to get the truck out, the hole in the rubbery crust becomes larger. As subsequent cars become mired in the hole and are pulled out, it continues to increase in size. In wet, cloudy weather, the dry, rubbery crust softens and breaks through under much lighter loads than it would under drier weather conditions.

Fig. 1. A thin rubbery crust of dry material covering saturated unstable soil.

CAUSES

Figure 2 illustrates how the road heaves much more than could be accounted for by the expansion from water to ice. The amount of heaving depends upon the rate at which the water is brought to the growing ice crystal by the capillary flow, and upon the length and severity of the winter.

Figure 3 shows some ice layers formed in the laboratory in a cylinder of clay soil. The surface uplift equals the total thickness of the layers. The ice lenses were formed by placing the lower end in water, insulating the sides, and freezing from the surface downward. This is really the way that the ground freezes.

In a laboratory specimen of which one half of the cylinder was clay and the other half sand, it was noted that there were a large number of ice lenses formed in the clay, while the sand was almost entirely free from the ice lenses. This may be accounted for by the fact that the sand and coarse material did not transmit the water by capillary action from the free water at the bottom of the cylinder to the area where the temperature was below freezing.

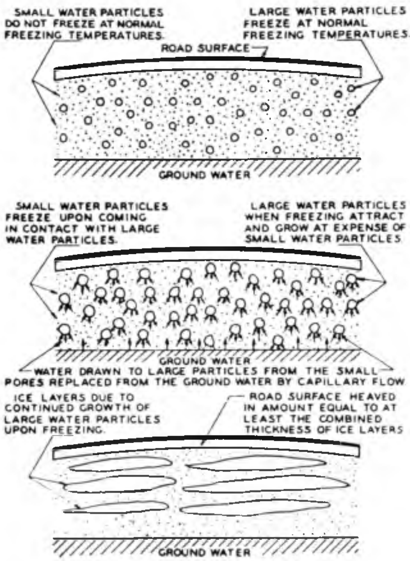

Fig. 2. Diagram illustrating the physics of frost heave.

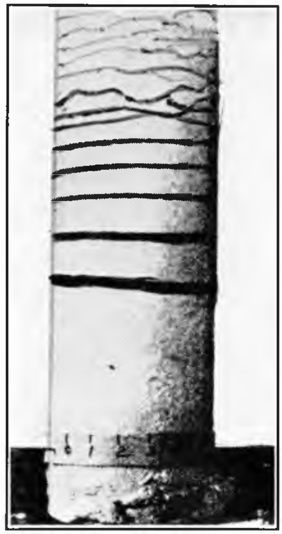

Fig. 3. Ice layers in artificially frozen clay cylinder. Surface uplift equals total thickness of ice layers.

Figure 4 is a photograph of a piece of soil which was taken from a frost heave at St. Peter, Minnesota. You will note the similarity of the ice bands in this naturally frozen soil to the laboratory specimens on the previous slides. The ice band at its thickest place in this soil was about one-half inch thick. We have observed them up to a thickness of ¾-inch.

When the road heaves so that bumps are formed, it must be that the conditions were more favorable for the formation of ice lenses where the bump is located than at other places along the road. This is what we have termed differential heaving. As far as winter driving is concerned, there would be no objection to heaving on a gravel road if the ground heaved uniformly throughout the length of the road, or if there was a gradual tapering from the portion not heaved up to the maximum amount of heave. The reason why we have bumps along the road must be that the conditions are more favorable for the growth of ice crystals at one place than at any other. This must be on account of the variation in soil texture or in the distance to the water table. In a crusted area, there is likely to be a considerable variation in both soil texture and elevation of water table, particularly in cuts through hills.

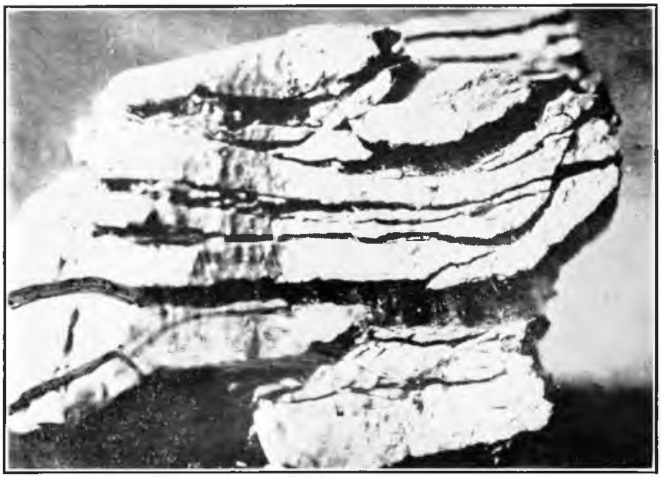

Fig. 4. Photograph of a piece of soil taken from a frost heave showing ice bands similar to laboratory specimens.

Frequently there is considerable difference in soil texture in the side of a cut. Some soils may contain a grain size that will transmit water rapidly and for a considerable distance. Very frequently sand seams carrying gravitational water, when coming in contact with capillary soils, furnish an abundant supply of ground water for the formation of ice lenses. If such is the case, then we have an ideal condition for the formation of ice lenses in the soil, that is, a favorable grain size for the growth of the ice crystals. Where a silt area is caused by sand, the sand supplies the silt with the necessary water for the formation of ice lenses. Most, if not all, of our severe heaving occurs where the soils of silt come near the surface of the road. The sand or coarser soils do not transmit the capillary water to a height great enough ordinarily to cause any trouble, and the finer grained soils, such as clays, do not ordinarily transmit enough capillary water during an ordinary Minnesota winter to result in much growth of the ice lenses. As previously stated, where the heaving is uniform, there is not much inconvenience to motor traffic during the months when the ground is frozen. In the spring, however, when the ice lenses thaw, they liberate a large quantity of water which is impounded by the frozen soil underneath.

CURES ON EXISTING ROADS

The objectionable features which need correction are the differential heaving and the spring break-up, frequently referred to as a frost boil. The heave is caused by the formation of ice lenses, and the methods of preventing heaving that naturally occur would be by preventing freezing, or removing the offending soil and replacing it with some other material, such as sand, which would not have a high capillary lift. On those roads where the heaving is not objectionable, but the spring break-up is serious, then the two methods of cure which might be followed would be to install some drainage system which would quickly remove the impounded water, or to increase the supporting power of the pavement or base in order to carry the loads over the underlying saturated, unstable soil.

The road diseases for which cures are needed are the heaves which are traffic hazards during the winter and the frost boils that occur in the spring. The elimination of the heaves would also eliminate the boil, for it results from the thawing of the ice lenses in the heave. In some places, however, the heave may be so uniform that it does not interfere with winter driving, and then the elimination of the frost boil condition is the only problem.

The formation of the ice lenses in the heave might be avoided by preventing freezing or by preventing the flow of the capillary water. The two methods of preventing freezing that have been considered are insulation and the injection of some chemical to lower the freezing point below temperatures likely to be encountered.

There has been some academic discussion about insulation, particularly under rigid pavements, but it has never seemed practical. Among the insulating materials that have been suggested are creosoted wood, straw, and peat. Somewhat more progress has been made in lowering the freezing point. Calcium chloride has been tried in a road near Midland, Michigan. It would appear that this method has possibilities.

The two methods of preventing capillary flow are to lower or remove the ground water supply, or to construct a layer of granular material, such as sand, which would have a low capillary lift. There are undoubtedly cases where the water in a sand stratum could be intercepted before it reached the road. It is very difficult to do this, however, in a glaciated area. The sand carrying the water to the silt does not lie in any plane, or have uniform thickness. It dips up and down. At the side of the road it may be too deep to reach with drains, and yet come quite near the surface of the road. The water in the sand may be under hydrostatic pressure. There is no use in going to the expense of drainage installations without testing with augers to find out where to place the drains. The drain should be placed slightly below the bottom of the water-bearing stratum. We have used this method to a limited extent in Minnesota. As a general rule, however, the water-bearing strata appear so irregularly that we can not be sure that the drains completely intercept the water supply to the silt.

The construction of a layer of granular material of low capillary lift has been widely used in Minnesota. This may be accomplished by digging out the offending soil and replacing it with the granular material; or, where the grade line permits, all or part of the granular material may be added to the surface of the existing road. Since 1928, there have been several thousand of these installations in Minnesota.

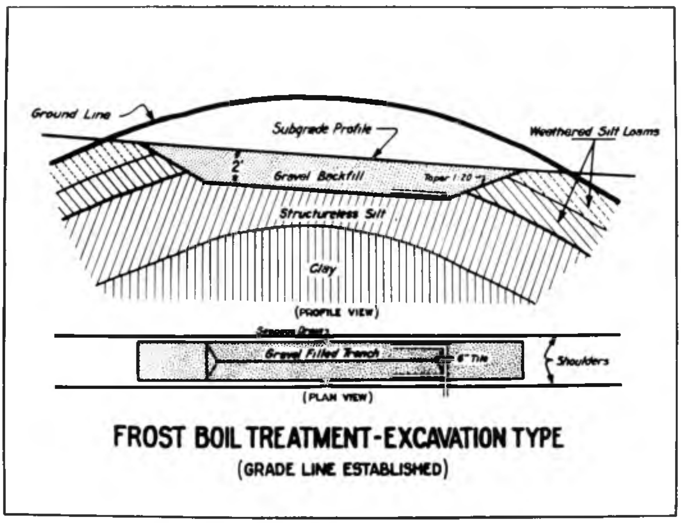

Fig. 5. A standard installation where the grade line is not changed.

Figure 5 illustrates one of our standard installations where the grade line is not changed. There was a tendency in our earlier installations to put them in too short, and, as a consequence, there was a bump at the ends. In order to prevent any possibility of a heave, it would seem that the granular backfill should go as deep as the frost penetrates. We have rarely noticed any heaving, however, where the fill was made 24 inches deep in the southern part of the state, or of increased depth up to 42 inches near the Canadian border. Although we have generally used tile drains, we are beginning to think they may not be necessary. There is apparently no appreciable amount of surface water entering the porous backfill when it is placed under pavements, bituminous surfaces, or stabilized gravel. Any ice lenses that would form would be under the gravel.

We have tried two methods of avoiding the spring frost boils in areas where the heave during the winter is not in itself objectionable. One method is to install drains so as quickly to remove the gravitational water resulting from the thawing of the ice lenses, and the other is to build a strong enough surface or base to carry the traffic over the areas where the natural soil is unstable in the spring.

We quickly found out that while drains in trenches backfilled with granular material did help the spring frost boil condition, they were too rough during the winter. As shown in this slide, the road surface heaved everywhere except over the trenches. On this particular road, in addition to the longitudinal there were transverse trenches every 30 feet, and you can imagine the opinion of the motorist. A short stretch of this on an otherwise good road would constitute what is frequently referred to as a hidden hazard.

In the spring of 1928, motor traffic between Chicago and the Twin Cities was held up by the frost boils on a road about 15 miles long in Minnesota. In order to carry traffic on at least one lane, the center 8 feet was excavated in the worst places to a depth of 4 feet, and filled with stones about as large as one man could handle up to near the surface. These acted as blind drains, as they had outlets through the shoulder. The results were satisfactory.

The other method of carrying traffic over frost boil areas is to provide additional strength to the base of surface courses. The soils engineer decides what additional thickness is necessary. He bases his decision on observations that he has made in that particular area. The additional base thickness is usually between six and twelve inches. Where the granular material is deficient in binder, some clay is added so as to increase the beam strength of the base. This type of treatment has two advantages over the excavation method in that it raises the grade line to a greater distance above the water table, and also takes advantage of the compacted crust which exists on the road.

In addition to selecting the depth of the base necessary over frost boil areas, the soils engineers also decide what thickness of base is necessary to carry traffic on the other portions of the road. The supporting capacity of the existing soil is a measure both of the type of the soil and of its water content. The men who decide the thickness of the base depend largely on field observations. It must be pointed out, however, that at the time they are placed in the field, they have a technical training in soils. It is fundamentally wrong to construct the same thickness of base over the entire road; and unless the supporting capacity of the underlying soil is uniform, the ideal is to have a road with the same traffic-carrying capacity throughout its length, and obtain this at the least possible cost. You will note on this slide that the gravel base thickness varies from three to nine inches.

PREVENTION OF FROST DAMAGES ON NEW ROADS

It is cheaper all-around engineering to build the new road in such a manner that frost heaves and frost boils do not occur. We know now the conditions under which frost heaves and boils are likely to occur. By adequate soils survey, information can be obtained so that the designer can provide necessary corrective measures.

We have found that most of the high joints in a concrete pavement resulting from the formation of ice lenses at the end of the slab are caused by the water leaking through the joint into the soil underneath. This saturated soil heaves more in the frost action than at the center of the slab. The two methods of preventing this are to construct some form of joint which the water will not pass through, or to construct a layer of non-capillary soil under the pavement. We have installed a number of special joints to prevent leakage. The first of these joints was built in 1934, and most of them gave satisfactory results in the winter of 1935-36, but we would not say that we have conclusive evidence that this is the ultimate solution of the problem.

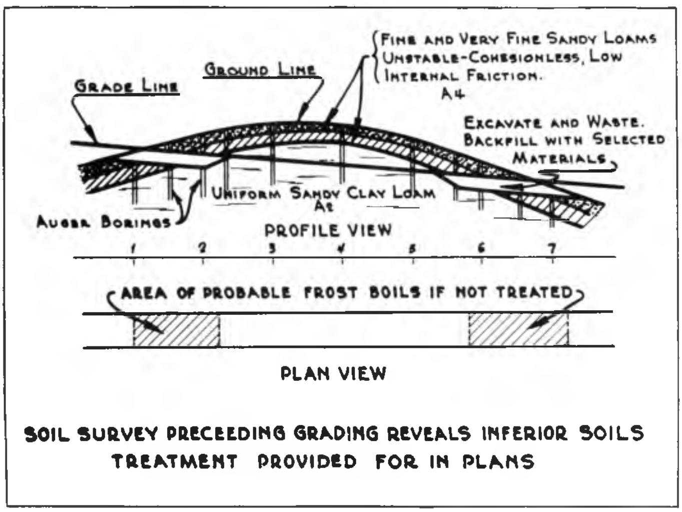

Fig. 6. Provision for excavating inferior soils and backfilling with silt materials.

We have noticed that there have been no high joints over the areas where corrections have been made with granular material to prevent frost heaves. This shows that the joints are smooth over the gravel, while there is a distortion immediately adjacent to the gravel. From further observations we are of the opinion that the high joints can be prevented by a granular layer under the pavement of not less than nine inches. We are now carrying on some experimental work in the field on this particular problem.

In many cases it does not seem possible to avoid the inferior soils by changing the grade line. In such a case, when soil surveys have located the areas where trouble is likely to occur, the necessary corrections such as excavating and backfilling with silt materials can be provided for in the contract for constructing the road. (Fig. 6.)

In a few instances we have had frost heaves in rock cuts. Upon investigation we have discovered that they were due to the fact that the rock was excavated in such a manner that it held water. This formed a perched water table, and if the fill over the rock was of a certain texture, then a favorable condition for the formation of the ice lenses would exist. This, of course, could have been avoided by taking out rock in such a manner that it would drain toward the sides. (Fig. 7.)

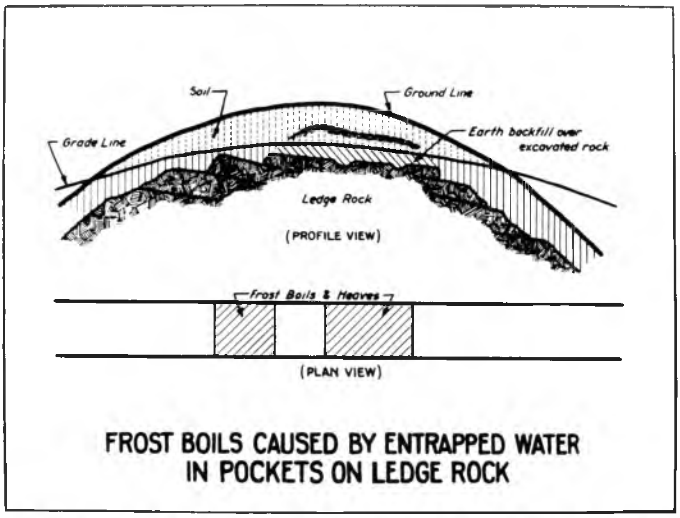

Fig. 7. Rock should be excavated so as to provide side drainage.

OTHER DRAINAGE PROBLEMS

Figure 8 shows a road condition which appears to be a frost boil. In this particular case, however, the bad places on the road were caused by seepage and occurred throughout the year. It was found upon investigation that the water was flowing on a relatively impervious clay toward a crack in the background. At the bad places in the road, the clay came up so near the surface of the road that the gravitational water seeping along on top of the clay softened the gravel road. This condition was corrected by putting the tile line through the pervious layer and slightly into the impervious layer so as to intercept the water before it reached the road.

Fig. 8. Road softened by seepage.

Figure 9 illustrates how such a drain should be placed. Unfortunately, the water-bearing strata do not occur in nature on a plane or uniform thickness as shown in this slide. As previously stated, the water in the sand may be under pressure, and if any is allowed to flow under the tile, it may later come near the road surface. Another cause of seepage troubles is to furnish a water supply for the growing ice lenses in some silty soil.

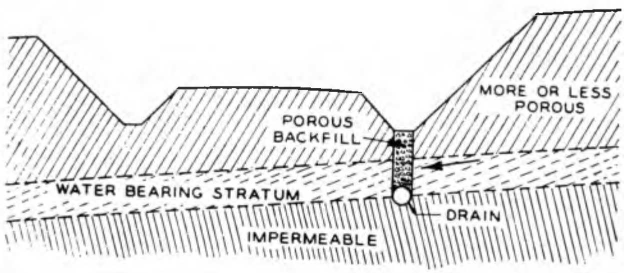

Fig. 9. Drains should extend through the entire depth of the pervious layer and into the impervious layer.

LOWERING THE TABLE

A practice in Minnesota is to have a high grade line, which is advisable in order to blow the snow off the road. The grade line is usually three feet or more above the bottom of the ditch. We have not used tile to any extent under the side ditches to lower the water table, or to supplement the water-carrying capacity of the side ditch. On silty soils we have found in fills and some cuts that frost heaves and frost boils may occur to as high a distance as twelve feet above the water table. It does not seem practicable to attempt to lower the water table by installing drainage in the side ditches to such a depth. On account of the traffic hazard of side ditches, it may be found advisable in the future to install drains in the side ditches and back fill the trenches with porous material.

SOILS ORGANIZATION

This is an age of specialization. There is so much known and unknown in each of the many activities connected with building and using highways, that no individual can hope to become a real expert on any phase of the work unless he concentrates his efforts. The solution of the frost and drainage problems requires a knowledge of soils. Any real expert on these subjects must have had a thorough education in the fundamental sciences in addition to practical experience. It is the opinion of the speaker that foundation questions which would necessarily include frost and drainage problems should be referred to men who have had special training and experience in their solution.

In Minnesota we recently placed soils men with some laboratory equipment in each of the eight construction districts. They have field assistants. At the central office or laboratory we also have a state soils engineer, an engineer in charge of gravel stabilization, an engineer on soils to advise designing engineers, and also two specially trained research engineers. The district engineers do not carry on research.

On state work this organization is responsible for all foundation and stabilization problems on old and new roads. On other than state work, they are in an advisory capacity only. Local engineers may consult them if they wish to do so. On account of the few trained men available, we have not been able to assist counties and townships as much as there has been a demand for.

For years roadbuilders have stressed the importance of drainage. It is common observation that most soils make better road surfaces and foundations when the moisture content is low. The difficulty has been that so little is known about how the excess water could best be kept out of the soil. The solution of our low-cost road problems waits for more knowledge concerning the utilization of our local soils for road purposes.