PRACTICAL APPLICATION OF ROAD SOIL SCIENCE IN CONSTRUCTION OF FLEXIBLE ROAD SURFACES

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SYNOPSIS

Flexible type bituminous surfaces should have a thin, relatively rich, waterproof wearing surface to withstand the abrasion of traffic The load must be carried by the foundation which may have sufficient natural stability or a stability built in by proper construction The direct causes for failures due to subgrade soils are divided into three major phases

1 Inferior stability which causes excessive deflection of the surface under load
2 Capillary properties producing moisture conditions in or immediately beneath the mat which may be detrimental without affecting subgrade stability
3 Non-uniform heaving by frost action

The report describes the methods used in Minnesota to correct objectionable soil conditions in the subgrade It is emphasized that soils work is highly specialized and can be carried on successfully only by specially trained men

That any type of road surfacing must be placed on a firm, well-drained roadbed is an old adage, but information concerning the fundamental principles to be applied in obtaining such a roadbed have been meager If a sufficiently firm roadbed could be obtained, any thin surface which would not shatter under traffic, and which would withstand the abrasive wear, should be sufficient

The thin, flexible bituminous surface has demonstrated in many places that it is suitable when placed on a satisfactory subgrade There is also ample proof that it is not a satisfactory surface when placed on the wrong kind of subgrade

The problem in the construction of flexible bituminous surfaces is not how to obtain slab strength, but how to construct a thin, relatively rich, waterproof wearing surface that will withstand the abrasion of traffic The support for this surface must be furnished by the foundation. This may involve the construction of such bases as partly stabilized gravel or lean bituminous mixtures

The direct causes for failures of bituminous surfaces attributable to subgrade soils may be divided into three major groups

1. Inferior stability, which causes excessive deflection of the surface under load

The lack of stability, as it affects the flexible bituminous surface, may be divided into three stages (a) when there is a slight deformation of the road surface, evidenced by cracks in an irregular network or pattern, commonly referred to as "alligator" cracks, (b) when there is a sufficient lateral flow of the subgrade soil under the wheel-load to form longitudinal ruts, (c) when the lateral flow of the subgrade soil is so great that the surface mat breaks under the load

2 Capillary properties producing moisture conditions in or immediately beneath the mat, which may be detrimental even though not materially affecting the stability of the subgrade

Moisture which may be brought to the surface of the subgrade soil and into the mat by capillarity or by the retention of surface water penetrating through the mat, may cause corrugations as a result of the lack of bond between the bituminous surface and the subgrade. Under some conditions this may be accentuated by the emulsification of the bitumen

3 Non-uniform heaving resulting from frost action, causing bumps in the road that often are traffic hazards

However, there are defects, such as cracking and rutting, that are a result of faulty design or construction of the bituminous surface and occur independently of the subgrade soil.

The responsibility for the design of the foundations to support flexible surfaces is placed, in the Minnesota Department of Highways, in the soils division, the activities of which may be roughly grouped as follows

1 Soil surveys *prior to surfacing* for the following purposes. (a) locating areas subject to frost heaves and frost boils and designing for corrective measures, (b) determining the thickness of gravel foundation necessary and locating materials where a partly stabilized gravel is to be used as a base, (c) locating pervious strata through which seepage water is flowing and planning corrective measures

2 Soil surveys *prior to grading* to locate objectionable soils and plan corrective measures, which may consist of either changing the grade-line or the location, or selection and elimination of soils during construction

Some of the corrective measures applied in Minnesota are dealt with in the following discussion

FROST HEAVES AND FROST BOILS

In Figure 1 is shown the manner in which the occurrence of frost boils is related to the soil layers and the position of the grade-line. As indicated, the grade-line passes through successive soil layers, and penetrates into a structureless silt which is particularly low in stability. Material of this type possesses practically no cohesion and very little internal friction, the two major properties essential to the stability of a subgrade soil In Minnesota this type of soil is largely confined to portions of the southeastern section of the state, where a windblown loessial deposit covers the glacial drift and portions of the unglaciated rock area

A further factor in this example is the presence of the lower clay layer, which is more impervious to the downward passage of water This causes a high ground-water level

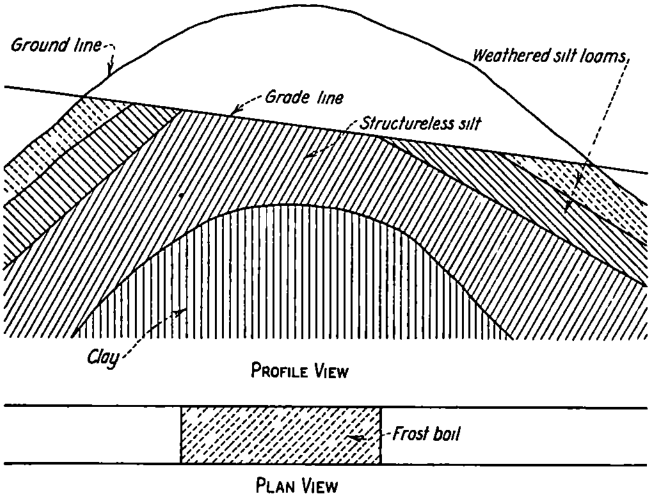

Figure 1. Relation of Frost Boil in Structureless Silt to Soil Layers and Position of Grade-line

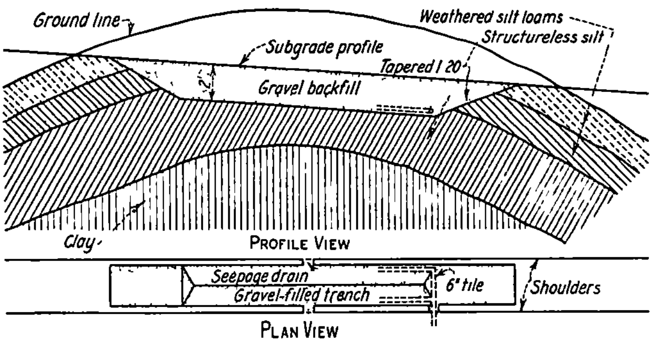

Figure 2 Excavation Type of Frost-boil Treatment, Used Where It Is Necessary to Maintain the Existing Grade-line

The elimination of such a condition is frequently accomplished by means of an excavation type of treatment, as shown in Figure 2 This is generally used where it is necessary to maintain the existing grade-line The affected area was excavated to a depth of 2 ft and backfilled with sand or pit-run gravel The pit-run gravel contains more sand than is required to fill the voids Tile outlets are placed at the lower end for the drainage of any moisture that may accumulate within the backfill

Where such excavation treatments are longer than 100 ft., seepage drains are cut through the shoulders and backfilled with gravel.

Figure 3 shows an excavation treatment in progress. The width of the trench depends largely on the type of surface and the class of highway. As a general rule, treatments of this type are somewhat wider than the width of the surface to be constructed. The depths vary according to the conditions involved.

It will be noted in Figure 2 that the treatment is confined to the structureless silt, and does not include the weathered silt-loam topsoil. There is a marked difference in the performance of these materials, although they do not differ much in texture. Apparently the structural development produced by the process of weathering is responsible for the better stability of the topsoils.

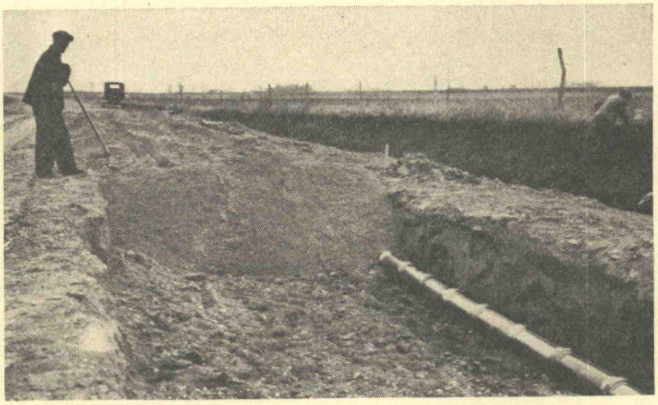

Figure 3. Treating Frost Boils by Means of Excavation Backfilled with Gravel

The greater part of Minnesota has been subjected to glacial action, with the result that the soil materials are usually a heterogeneous mixture. Severe heaving is often a result. At one place, two very sharp frost heaves had been observed. Subsequent borings revealed that a thick band of silt lay embedded within the heavier clay-loam till. Above a portion of this silt occurred an extensive pocket of fine sand. The silt approached the grade elevation at two separate points which coincided closely with the points where heaving had been noted. The accumulation of surface water in the fine sand supplied the silt band with a sufficient amount of water to produce excessive heaving.

In an effort to remedy the frost-boil conditions as cheaply as possible, it has sometimes been the practice to construct narrow trench drains along the center of the road. This has been done to facilitate the escape of surplus water during the spring break-up. However, where the trench has been dug through highly capillary soils, the result may be that this material at the sides heaves badly while the granular material used for backfill does not heave, and as a consequence there is formed an objectionable depression in the center of the road, in addition to the bumps caused by the numerous transverse trenches

In some portions of Minnesota, particularly in the northeastern area, there are numerous outcroppings of ledge rock In this area we find many severe frost heaves. Many of these occurring on bituminous or gravel roads develop into severe frost boils during the spring break-up. It is frequently found that the fault may be traced to the irregular contour of the surface of the underlying rock, as shown in Figure 4 In grading operations it has been the practice, when cutting through the ledge rock, to excavate such rock to an elevation approximately 1 ft below the final grade-line The subgrade is then built up to grade with soil material

Often the excavating operations result in forming depressions or pockets in the rock surface in which surface water and moisture seeping

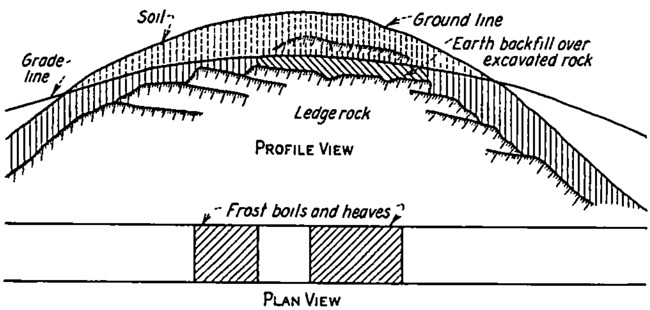

Figure 4. Frost Boils Caused by Entrapped Water in Pockets on Ledge Rock

through crevices and faults may accumulate in sufficient amount to saturate the soil Excessive moisture gathered in this fashion during the summer and fall is especially favorable to frost heaving Likewise in the spring the depressions effectively retard drainage As a result, the break-ups are protracted well into the summer Remedying such conditions is generally quite expensive, since it usually involves blasting It may be possible to eliminate such failures by replacing soils producing heaving with porous materials not affected by the presence of water

THICKNESS OF GRAVEL BASE

One of the functions of the soil-survey work is the determination of the thickness of gravel base necessary for adequate support. Figure 5 is an example of its application to construction operations Before construction of a bituminous surface on a given project, we make a complete soil survey, determining the classes of soil composing the subgrade and their relation to general drainage conditions The condition illustrated represents a project in the northcentral part of the state where topsoils developed under frost conditions were encountered.

In the type shown, the upper horizons consist chiefly of fine sandy loams and very fine sandy loams which contain a considerable amount of coarse silt Generally there is a relatively low clay content, so that the materials possess very little cohesion Likewise, because of their fineness, there is not a great deal of internal friction The result is that these soils become decidedly unstable when saturated The unweathered subsoils generally have a better gradation and better cohesive properties When the grade-line lies in cuts or fills shallower than approximately 2 ft, there is a strong possibility that failure will ensue.

In cuts deeper than 2 ft, where the grade-line will lie in the unweathered subsoils, or on fills composed of these subsoils, there is much less likelihood of failure For this reason it has been our practice to vary the thickness of the base course in conformity with the class of

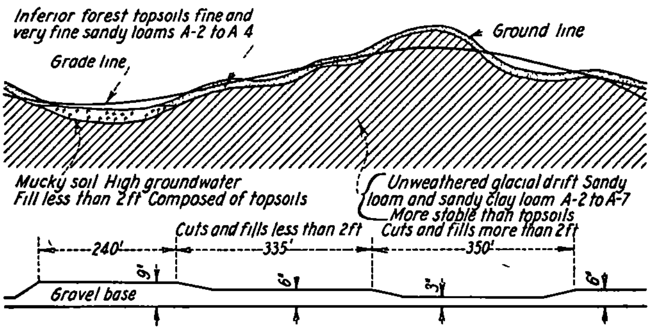

Figure 5. Variation in Gravel-base Thickness Dependent on Subgrade

subgrade soils It will be noted that the thickness is changed in increments of 3 in While it may be difficult to classify the soils so accurately as to state with authority that a base should be 3 or 4 in thick, still we may be sure enough of the comparative stabilities to state whether the thickness should be 3 or 6 in The selection of the thickness of base depends largely on past experience in the performance of the various materials under different field conditions. We have also endeavored to make laboratory analyses of samples representative of these materials, and to correlate laboratory results with the field information.

On the project referred to, having a total length of about 12½ miles, the base thickness was changed a total of 25 times.

Field observations indicate that there is a very definite relationship between the condition of a thin bituminous mat and the presence of an intermediate base course over the heavier soil subgrades In Figure 6 are shown the results of a study made in 1933 to determine the effect of gravel base on the surface condition The survey embraced a seven-mile project, and cross-sections were taken at intervals of 0 2 mile The 116 observations analyzed were confined to approximately the center 16 ft The diagrams show strikingly the effect of the gravel base Of the seven points over gravel base that were slightly rough or rough, in four places the bituminous mat contained what appeared to be an excess of bitumen and a cleavage plane existed between the mat and the base At 42 of the 46 observations at points where there was no gravel base there appeared to be a cleavage plane between the mat and the subgrade This cleavage plane was found to exist at all points where the surface was classed as rough or very rough

In some instances where gravel has been placed on the road surface to form a base for subsequent bituminous treatment, natural gravel materials have failed to consolidate sufficiently to provide a firm foundation by the time the bituminous surface was to have been applied Where

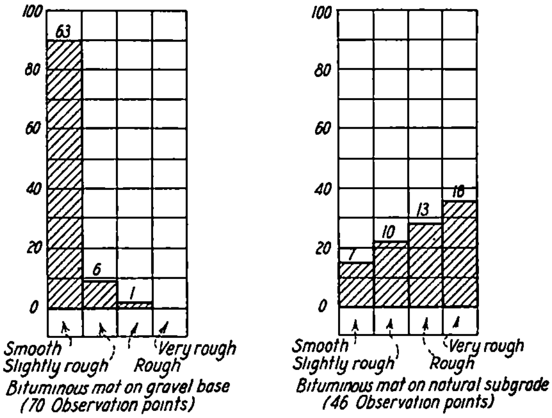

Figure 6 Results of Bituminous-mat Survey, Showing Effect of Gravel Base on Surface Condition.

this happened it was necessary to supply binder in the form of either extra bituminous material or cohesive soil material We are now making an effort to avoid the recurrence of such conditions When it becomes necessary to place a heavy layer of gravel, we are attempting to select our materials to conform to specifications that will result in the desired compaction The curves in Figure 7 show the gradation established for stabilized gravel bases The lower curve will result in consolidation, although with not as much density as the stabilized band The curves for stabilized gravel were developed following a study made in 1933 of a number of existing gravel surfaces Samples were taken at many points at which the condition of the surface was noted The factors considered in judging the relative stability were performance under both wet and dry weather conditions and the ease of maintaining a smooth-riding surface

The grading curves were developed from laboratory analysis of from 10 to 12 roads that appeared to have the best qualities Along with the gradation shown, it was found that the materials passing the No 40 sieve had elasticity indices between 5 and 15 For gravel courses that are to be used as wearing surfaces it is desirable that the maximum density be obtained However, when the gravel course will serve merely as a base for a bituminous surface, it is not desirable that the mixture contain quite as high a proportion of binder

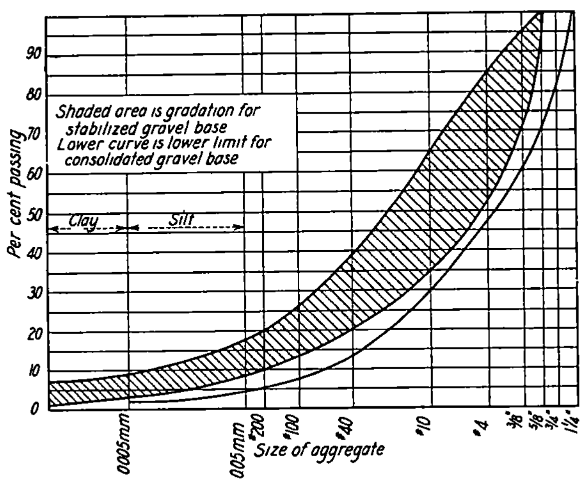

Figure 7. Gradation Established for Stabilized or Consolidated Gravel Bases

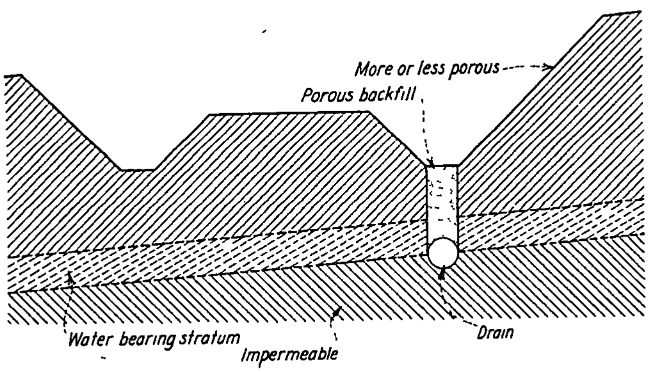

Figure 8. Underdrain Eliminating Seepage Condition Should Be Placed Below Plane of Seepage. Note porous backfill.

ELIMINATION OF SEEPAGE CONDITIONS

Another use, previously mentioned, of soil surveys prior to surfacing is in the elimination of seepage conditions

The manner of placing an underdrain to eliminate a seepage condition is shown in Figure 8 It is essential that the drain be placed low enough so that it will be below the plane of seepage It is also necessary that the trench above the drain be backfilled with material more porous, if possible, than the stratum through which water is being carried Where seepage conditions occur, it is generally advisable that a detailed investigation be made in order to determine the exact source of water and to design properly the corrective treatment to be applied Without such preliminary information, the work of placing drainage systems would have to be undertaken blindly and might prove ineffective

SURVEYS PRECEDING GRADING OPERATIONS

The principles previously illustrated and discussed are followed in making soil surveys preceding grading operations, so far as treatment of doubtful areas is concerned The work is chiefly a problem in locating materials likely to cause defects In attacking this type of survey the soils engineer is provided with a profile showing the ground-lines on the proposed location as well as a tentative grade-line Auger borings are

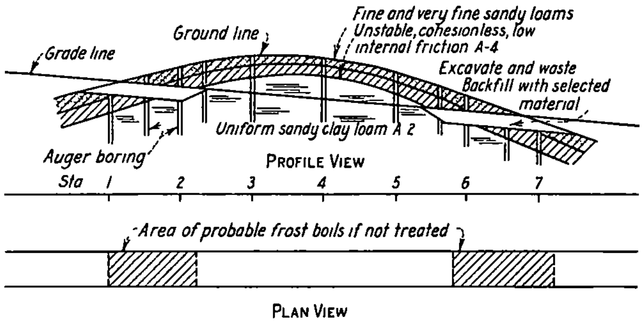

Figure 9. Excavation and Backfilling Provided Where Soil Survey Preceding Grading Reveals Inferior Soils

then made, particularly in sections likely to be in cut. Generally these borings are taken at 100-ft intervals, but when materials of questionable character are encountered, the interval is reduced in order to trace out the limits

In Figure 9 is shown a condition where the grade-line passes through topsoils of the inferior types discussed previously. From past experience with this class of material, it is reasonably certain that frost boils will occur in the areas shown on the plan view The soils engineer may recommend the removal of these materials within the areas likely to be affected He will also recommend the class of material to be used in backfilling

Another variation of this problem, where the topsoils are of a relatively stable nature as compared with the unweathered subsoil, is indicated in Figure 10 Borings at 100-ft intervals here revealed a stratified condition of subsoil, with some poor silt materials If the tentative grade-line were placed in the position indicated by the broken line, it is probable that frost heaves and boils would occur over the shaded areas in the plan view The soils engineer will recommend an adjustment in the grade-line to carry it well above the inferior subsoils If the grade-line could not thus be adjusted, it would be necessary to provide for removal by excavation of the subsoil. With that in mind, when making a survey, the soils engineer would add sufficient borings to determine with reasonable accuracy the outline of the poor soil material

When a soil survey of this nature is being made, the boring data are plotted on the ground-line profile Having taken the necessary borings throughout the project, the soils engineer will select representative samples of all the various types of materials encountered Such samples are submitted to the laboratory for analysis, and the results are studied by the soils engineer with reference to the conditions on the project

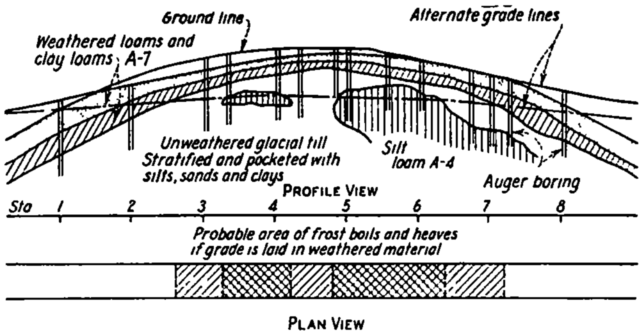

Figure 10 Grade-line Adjusted Where Soil Survey Preceding Grading Reveals Inferior Subsoils.

Detailed recommendations are prepared for specific treatments, and this information is submitted to the construction division to be incorporated in the plans.

Thus far, we have not been able to carry out this procedure on all of our contemplated grading projects, but we are doing it where time permits

SPECIAL SOILS ORGANIZATION

The Minnesota Department of Highways has set up a special soils organization, consisting of an engineer of soils and a principal assistant in the main office, and a soils engineer in each of the eight district engineers' territories Enough laboratory apparatus is being placed in the district headquarters to permit making routine tests on soils

The district soils engineers are responsible for the soils work in their districts The district engineer advises these men where to work, as he knows where improvements are going to be made, but the technical supervision is furnished entirely by the soils engineer No improvements mentioned are made unless a plan has been prepared

The soils engineer at the central office is a member of the division of tests, inspection and research The work requires a special type of man who has had a thorough education It is desirable, if possible, to obtain men who have completed a regular engineering course, have had some experience and have taken graduate work in soils The benefits to be gained by the work of a good soils organization are so great that no chances should be taken in trying to carry on this work with men who have not had adequate training Furthermore, soils work can be carried on successfully only by men who are not burdened with administrative and unnecessary detail work