PART I

WHAT SUBGRADE INVESTIGATIONS HAVE SHOWN DURING THE PAST YEAR

I B Mullis

U S Bureau of Public Roads, Washington, D C

During the past year research has been conducted on various phases of the subgrade problem and detailed reports of the work will be made under the following headings

1 The relation of penetration to bearing area
2 Some effects of temperature and granular materials on subgrade moisture
3 Determination of the percentage of water frozen in subgrade soils
4 The effect of granular materials in stabilizing plastic clay under macadam pavements
5 The practical field tests for subgrade soils
6 Heaving and frost boils

1 *The relation of penetration to bearing area*—The purpose of this investigation was to determine whether any relation existed between the supporting value of a soil and the size of the superimposed area, and if so, to establish definitely this relation in order that supporting values obtained by using a small area might be properly interpreted in terms of the supporting value that would be offered to large areas, comparable with those occurring in practice

The materials used for experiment consisted of quantities of soils classified by the U S Bureau of Soils, as Susquehanna clay mixed with varying proportions of Potomac sand In all, five different mixes were used, ranging from pure Susquehanna clay, to soil made up of one part Susquehanna clay and five parts sand The size of the bin in which the tests were made was six feet square and the soil tamped to conform as nearly as possible to the same material as found in nature The size of the circular bearing blocks used ranged from 1 square inch to 9 square feet. Each test was repeated until checks within close limits were obtained

As a result of this investigation, the following conclusion has been reached *The relative penetration of two bearing blocks under the same unit intensity of load is to each other as the square roots of their respective areas* Further tests will be conducted to test the validity of this conclusion under working conditions

2 *Some effects of temperature and granular materials on subgrade moisture*—From a large number of samples taken from the surface of exposed soils and also from the upper depths of subgrades under pavements it has been found that the maximum moisture content during cold weather is usually higher at the surface than at the lower depths Exceptions to this rule, however, were encountered during last winter in field work done in the states of Ohio, Iowa, and Minnesota During

certain periods, in the states mentioned, the maximum moisture content did not occur in the upper layers of the subgrade, but at much lower depths, thereby apparently contradicting the results of many experiments in the vicinity of Washington, D C. At that time the reason given for these differences was that the rate of evaporation had exceeded the rate of capillary movement of the moisture, but there was no definite proof For the purpose of investigating this phenomenon, glass tubes were filled with soils, the lower ends subjected to free water and the soils allowed to take up capillary moisture until constant weight had been reached The soils were then covered with a rubber blanket over which was laid crushed ice and after two days exposure, moisture samples were again taken and it was found that soils made up of pure clay had increased in moisture content from 4 to 6 per cent After a further exposure of 16 days it had been increased from 6 to 8 per cent The same clay soils were also covered with 2 inches of coarse and fine sand, respectively, which reduced the moisture content in some cases to as low as 1½ per cent

During the experiment it was found that the evaporated moisture from the soils was condensed on the lower surface of the rubber blanket and dropped back on the surface of the soil until free water had accumulated on the surfaces It has also been shown by another series of experiments made at the Arlington Experimental Station that the result of the increased surface tension of a clay soil, due to lowering of the soil temperature, has been sufficient to increase the moisture content as much as 6 per cent As a result of these experiments and observations, it is believed that these phenomena are responsible for the high moisture contents of certain soils during the winter and spring months These results are also in full accord with known laws of physics governing condensation and evaporation It is therefore concluded that moisture content in a road subgrade may be increased through (1) increased surface tension from lowered temperature and (2) condensation of vaporized moisture due to lowered temperature

During last summer, humidity determinations were made of the soil air in shrinkage cracks between pavements and the subgrade The relative humidity readings ranged from as low as 81 per cent to 100 per cent When the temperature of the lower surface of a pavement reaches the dew point of the air, dew is deposited on the subgrade If the temperature of the surface of the subgrade is at, or below, the dew point of the air, condensation takes place in the subgrade itself, thereby permitting only the minimum evaporation to occur When the subgrade is frozen to considerable depth, capillarity is arrested and since evaporation may occur at all temperatures, evaporation although much decreased, produces a drying of the surface subgrade which explains the reason for the low percentage of moisture found in the upper depths of the subgrade last winter in the states mentioned

It is believed that the introduction of such granular materials as sand, gravel, cinders, etc, into the subgrade not only tends toward reducing the capillary tension in the subgrade soil, but allows the condensed moisture *to be deposited on a subgrade made up of materials whose bearing value is not so decreased by moisture*

3. *Determination of the percentage of water frozen in subgrade soils* —The object of this investigation was to determine the effect of certain soils on the percentage of moisture frozen. The method used was that known as the dilatometer method and the percentage of moisture frozen was measured by the expansion of the ice crystals on freezing The medium in which the freezing was done was ligroin The results of these tests indicate that the percentage of water present varies from 0 per cent to 100 per cent. The only material in which 100 per cent of the moisture could be frozen was clean Ottawa sand. This sand, upon being ground so that it would pass a 200-mesh sieve, would permit only 70 per cent of the moisture to be frozen As a whole it is indicated that the size of the particles is one of the factors controlling the amount of water frozen in the soil Contrary to the general belief, the soil itself shrinks upon cooling, and it is only the water which crystallizes and seemingly causes the soil to expand The velocity of the freezing in soils is also different In some instances the freezing is very rapid while in others it is very slow.

4 *The effect of granular materials in stabilizing plastic clay under macadam pavements* —This experiment was made to determine just how and why certain clay soils pass up through the voids in macadam roads, and what is necessary to stabilize such clays For this purpose a highly plastic clay was used and layers of broken stone were placed on it and subjected to blows from a 120-pound plunger directed on a bearing block 1 square foot in area The materials used for preventing the flow of the clay up into the voids of the stone were fine sand and cinders The results of these tests seem to indicate that the thickness of sand or cinders necessary to be used in connection with 1½-inch stone was about 2 inches This fine material seemed to act as a bridge across the voids in the stone In no case was there any mixing of the sand or cinders with the clay, and failure of layers occurred in the form of vertical shear through the stone It is through this vertical shear plane that the clay makes its passage The passage of clay through the compacted gravel roads always occurs through vertical shear planes and not by actual passage through the compacted material The position of shear planes through gravel roads may be located by the appearance of increased capillary moisture as shown on the surface These are sources of frost boils so prevalent on many gravel and macadam roads

5 *Practical field tests for subgrade soils* —The major findings of the Bureau's subgrade studies as followed by A C Rose of the Bureau of Public Roads, District No. 1, Portland, Oregon, follow:

1 The field moisture equivalent test seems to give results practically identical with the standard laboratory methods
2 A moisture equivalent percentage of 20 seems to be critical in respect to the bearing power of a soil. When the moisture equivalent percentage is less than 20, the density and possibly

the bearing power of a soil do not seem to be decreased perceptibly by the addition of water until the moisture content is made greater than the total voids in the soil

3 Defining the term "stability ratio" as the actual moisture content percentage of the soil divided by its moisture equivalent value, the field investigations in the states of Oregon and Washington seem to indicate that the bearing power of a soil is relatively low when the stability ratio is greater than unity When the stability ratio is less than unity, existing subgrades are generally well compacted, firm, and hard The application of the stability ratio is limited to soils with moisture equivalent percentages greater than 20

4 When the moisture equivalent percentage of a soil is greater than 20, the moisture equivalent percentage seems to represent the extreme limit that the moisture content of a subgrade should be permitted to reach

5 The lineal shrinkage percentage test detects poor subgrade soils which pass a favorable moisture equivalent test or vice versa

6 The lineal shrinkage of a soil with a moisture equivalent percentage of less than 20 is usually too small to be measured According to a computed curve, the shrinkage will be zero when the moisture equivalent percentage is 15 4 This curve was computed from the results of 176 tests An original and check run was made for each test and the average result used For all practical purposes it is believed that zero shrinkage may generally be assumed to occur when the moisture equivalent percentage is equal to or less than 20.

7 When the lineal shrinkage percentage is less than 5 per cent, the subgrade soil does not seem to require special treatment or protective measures to prevent the shrinkage or swell from reducing the life of the road surfacing

Studies made by J. T. Pauls on the Columbia Pike, Virginia, indicate that a subgrade volume change of as much as 10 per cent, corresponding approximately to 3 6 per cent lineal shrinkage, is detrimental to the pavement The addition of granular material to such a subgrade increases its supporting value and modifies the effect of any volume change

The percentage of capillary moisture as determined by examination of a subgrade sample by the present laboratory test does not represent the maximum amount of moisture that will be held in a particular subgrade The maximum moisture content of the subgrade under a pavement is not very definite on account of the many variables involved.

6 *Heaving and frost boils*—Observations on the heave of concrete pavements were made at 13 different locations, six of which were in Iowa and the remainder in Minnesota.

At these different stations, a variety of soil conditions was encountered ranging from sands to heavy clays. The major conclusions derived from the results are as follows

1. Maximum heave observed was 7 3 inches
2 The nature of the underlying soil or subgrade does not appear to influence the amount of heave nearly so much as do the drainage conditions Large heaves were measured where subgrade conditions were sandy as well as clayey, and small heaves were also measured under these conditions

At test station No 6, Duluth, Minnesota, numerous springs exist beneath the surface of the road and although an attempt was made to take care of the free water by using drain tile, very marked heaving occurs here each winter in spite of the fact that the drain tiles are operating throughout almost the entire year A large amount of rock and gravel was put here before the pavement was laid

SAND-CLAY ROAD INVESTIGATIONS

C M Strahan
University of Georgia, Athens, Georgia

Reviewing the 1923 report of this Committee, it appears that the statement of principles and methods therein need not be repeated

Much thought during the current year has been given to the idea that road soils and other pavements made by the formation of slabs from loose aggregates owe much of their durability and traffic service to mass action and internal physical bond The effort has been made to devise a means of studying this action in some of its phases in the laboratory and in the field After considerable disappointment with trial apparatus, an appliance has been devised which promises well and which, if not already in satisfactory shape, may be modified further. A brief description of the test follows

THE DISC SHEAR APPARATUS

1 Discs of relatively large diameter and thin vertical dimensions are prepared under uniform conditions of mixing, tamping, and final compression Present standard uses a disc 4 inches in diameter and 1 inch thick, mixed up in moist condition for soils, thoroughly tamped and finally compressed under a total load of 25,000 pounds, or very nearly 2,000 pounds per square inch
2. The discs are dried to constant weight
3 The test is made by centering the disc enclosed in a snug fitting steel ring over a circular die opening of ¾ inch diameter, above which a steel plunger, accurately aligned with the die and ⅝ inch in diameter, is made to force or punch a plug of the material through the die ring
4. On road soils, the test is made first on the dry discs, and is followed by tests of similar discs containing specific percentages of water
5 The water is added and diffused through the discs as follows The surface of the disc is covered with blotting paper, well