ders of sufficient width to permit parking off the pavement when repairing tires. This is sometimes quite expensive, but not as expensive or dangerous as blockading the pavement slab with parked automobiles. The Indiana Highway Commission is now constructing all its concrete pavement with 8-foot shoulders, with a slope of ½″ per foot toward the side ditch in order to help the drainage. Traffic cannot park on the shoulders when the ground is soft, but fortunately that is not usually the condition when the traffic is the heaviest and the pavement is being used to its maximum.

Another reason for constructing wide shoulders on our highways is the necessity for snow removal. We have within the last few weeks had over half the area of Indiana pointed evidence of that factor. If narrow, cramped shoulders are constructed, on a plea of economy, there is provided no place to which heavy snow from cuts can be either plowed or shovelled from the pavement in order to let the traffic through.

And, within the last few days, we have seen the necessity for pavements to be constructed above the flood water levels. If that can be done at any reasonable cost, the pavements should be made available for use when the need is greatest and often tragic. Many times entire communities would be marooned, so far as automotive traffic is concerned, except for pavements and bridges constructed above the flood waters which are veritable life savers to many hundreds of people. And the pavement slab costs the same, whether constructed above or below the height of the floods.

THE DESIGN OF A LARGE TILE DRAINAGE SYSTEM

By H. C. Morrison, Gibson County Surveyor

In order to understand and properly design a tile system, a certain knowledge of soil physics is essential. Under the classification of soil particles, we might have fine gravel, coarse sand, medium sand, fine sand, very fine sand, coarse silt, medium silt, silt, fine silt, and clay, in which the size of the particles may vary from 1 to 2 millimeters in diameter down to .005 to .0001 millimeter in diameter.

The size and arrangement of the soil particles and of the voids between them plays a very important part in agriculture, since upon them depend the aeration of the soil, the rate of percolation and of capillary action, and the available supply of moisture and plant food.

A soil made up entirely of particles 1 millimeter in diameter would contain approximately 15,600 particles in a cubic inch with a total surface area of ½ square foot, while one made up entirely of particles .0001 millimeter in diameter would contain approximately 15,625,000,000,000 particles in a cubic inch with a total surface area of 5,450 square feet. Soils are composed of all sizes of particles, and in an average agricultural soil the total surface area of the particles in a cubic foot of soil is about 70,000 square feet.

The particles of an average soil are of all sizes and shapes and are mixed together in every conceivable manner, bound together by colloids; that is, the very finest particles of mineral or organic origin which assume a gelatinous condition when mixed with water. The spaces between the larger groups are filled with smaller ones and these in turn have still smaller particles between them and so on.

The surface soil in wet climates is made up of coarser particles than the layers beneath, because of the action of percolating water which carries the smaller particles downward. It is also more pervious because of the granulating effect of plowing and the action of plant and animal life in opening the soil. Between the soil particles are air spaces or pores which are as irregular in size and shape as the particles themselves. The individual pores in coarse-grained soils are larger than in fine grained soils, but the total pore space or porosity per unit volume is greater in the fine grained soils. Also, the more irregular the shapes of the soil particles, the greater the porosity. The porosity of soil increases with an increase of organic matter content. The action of bacteria on the organic matter results in the formation of colloids which, through their cementing properties, cause a granulation of the soil particles.

The porosity in soils varies from about 45 per cent in sand to 65 per cent in peat, with 60 per cent in brown silt loam in loose soils and about 10 per cent more in compact soils.

Soils of medium porosity are better adapted than others to most crops. Soils with large pore spaces permit too rapid percolation, aeration, and evaporation and are readily blown away by the wind while those with small pore spaces, such as clays, do not permit sufficient percolation and aeration for the best growth of crops.

Moisture in Soils

There are three kinds of moisture, or water, present in all soils—hygroscopic, capillary, and gravitational.

Hygroscopic Moisture. Hygroscopic water, or moisture, in soil is that moisture which condenses upon the surface of thoroughly dry soil particles when exposed to air. The amount of moisture which is thus condensed depends upon the temperature and humidity of the air and on the total surface area of the particles exposed to the air. The amount of moisture, expressed as a percentage of the dry weight, which a soil will absorb from a saturated atmosphere at a given temperature is called the hygroscopic coefficient. The moisture forms an extremely thin film over the surfaces of the particles. The larger the percentage of colloids in a soil, the larger the hygroscopic coefficient will be. This varies from ½ per cent in the case of coarse sand to 11 per cent in the case of clay loam. The thickness of the hygroscopic film is extremely thin. In fact, it is so thin and is so firmly held by adhesion to the soil particles that it cannot be used by the roots of plants, nor is there any movement of water from one particle to the other.

Capillary Moisture. The second kind of water or moisture present in soils is capillary water. When a small amount of water is added to a soil which already contains its maximum amount of hygroscopic moisture, the thickness of the soil moisture film is increased and, where particles of soil come in contact, the film is continuous from particle to particle. Water can now move from one particle to another, though the movement is quite slow. This additional moisture can now be used by the roots of plants but the amount is insufficient to satisfy their needs. The hygroscopic moisture content of a soil must be increased about 50 per cent before there is sufficient moisture in the soil to prevent the plant from wilting or dying. This percentage of moisture is called the wilting coefficient.

As water is added to a soil with a moisture content equal to the wilting coefficient, the soil moisture film increases in thickness, the water is held less firmly by the particles, and the capillary movement is easier and more rapid. The capillary movement may take place in any direction, though it acts more readily downward than upward since it is then working with the force of gravity instead of against it. The capillary pull depends upon the curvature of the moisture film—the greater the curvature, that is, the smaller the radius of curvature, the greater the pull. If the curvature of the films on all particles is the same, the water will be in equilibrium, and there will be no movement. The greater the difference between the curvature of film on adjacent particles, the more rapid is the capillary movement. The smaller the amount of capillary water in a soil, the thinner is the moisture film, the greater is its curvature, and the stronger is the capillary pull. As more and more water is added to a soil above the wilting coefficient, the thicker becomes the moisture film, the larger the radius of curvature, and the less the capillary pull. Presently the point is reached where the capillary pull equals the gravitational pull, and the point of maximum capillary capacity or moisture holding capacity is reached. The moisture in the soil at this point is also expressed as a percentage. If additional water is applied, it will slide off the moisture films and be carried downward along the path of least resistance by the action of gravity.

The soil immediately above the water table contains the most capillary water and, as the surface is approached, the amount of capillary water which the soil can retain becomes less and less because the capillary pull decreases as the resistance above the water table increases. The maximum capillary capacity of soils varies with the depth. For average loam soils, it is about 20 per cent.

The capillary water is that which is used by plants in their growth. While the amount of water needed varies considerably for different plants, that required for the best growth of common crops varies from 40 to 60 per cent of the maximum capillary capacity of the soil. This percentage is called the optimum water content.

Gravitational Water. The gravitational water of soil is that water contained in soil between the maximum capillary capacity and the point of saturation. This is the water which is injurious to plant growth and should be removed by drainage. The percentage of gravitational water varies with the depth below the surface of the ground, the surface soil under saturated conditions containing a greater percentage of gravitational water than the subsoil.

The rate at which gravitational water moves downward through the soil depends on the size of the soil particles, the size of the pore spaces, the granulation of the soil, the organic matter in the soil, and the openings in the soil made by cracks, by the burrowing of earth worms, and by the decayed roots of plants. The first mentioned factor is the most important one. In coarse-grained soils, percolation is much more rapid than in fine-grained soils notwithstanding the fact that the latter soils are more porous. Both capillary movement and percolation are more rapid when the soil is wet. Thus, directly after a rain, on soil which is dry, the downward movement is slow until the soil becomes moistened; then percolation takes place more freely.

The rate of percolation is the important factor in the design of drainage systems. Since this varies for different soils, it is necessary to study the soil structure in each case. A soil auger should be part of the engineer's equipment and samples of the subsurface and subsoil should be taken at representative places and the texture of the soil studied. If possible, laboratory test should be made on the percolation of the water through the soil samples and the results compared with those obtained from some soil taken as a standard or, better still, with samples taken from a field which is satisfactorily drained by a system of known depth and spacing of tile. In this way, in the course of time, the engineer can obtain a large amount of valuable data on the percolation of water through the various types of soil.

All plants are dependent for their growth on the following elements: carbon, hydrogen, oxygen, nitrogen, phosphorous, potassium, magnesium, calcium, sulphur, and iron. Some plants have the power to extract nitrogen from the air if there is not a sufficient amount of nitrogen available in the soil. The nitrogen is extracted from the air by nitrogen gathering bacteria which live in the nodules in the roots of the plants. These elements cannot be used in their original form but must be changed into soluble phosphates, nitrates and salts of potassium, magnesium, and calcium, by the action of bacteria which live in the soil and decompose the organic matter into organic acids such as carbonic and nitric acids.

All plants grow by the food furnished by the elements above mentioned. The fine root hairs of plants absorb by osmosis the plant food from the soil which passes up through the plant in solution and is absorbed into the growth of the plant, the water in turn being transpired through the pores in the leaves of the plants.

Purpose of Underdrainage

The foregoing discussion is given only as a preliminary to show why we should have underdrainage and to lead up to the results to be expected by it, which may be summarized as follows:

1. The removal of gravitational water.
2. An increase in the amount of available capillary water.
3. An increase in the volume of soil from which the roots of plants can obtain food.
4. An increase in the temperature of the soil.
5. The aeration of the soil.

It is important that all free or gravitational water should be removed in most soils to a depth of 3 or 4 feet below the surface of the ground so as to obtain the maximum benefit from the capillary water which is essential to plant growth. The depth to which the water table is best suited to plant growth depends upon each type of soil and should be determined by a careful study of the soil and by comparison with well drained tracts of similar types of soil in the vicinity, if such there be.

There is an increase of available capillary water when the water table is lowered. If the water table is only down one foot, then the capillary action is limited to the soil one foot below the surface; but if the water table is 4 feet below the surface, much more capillary water is available for plant growth.

The increase in available plant food supply in an underdrained soil is due to the fact that the roots of the plants will not penetrate or live in a permanently saturated soil stratum because of the absence of air, whereas in the underdrained soil there is a larger volume of soil from which to draw plant food and consequently a more healthy plant is produced. Not only is more plant food available but the rate at which it can be assimilated is increased because of the higher temperature of the soil and the larger supply of air.

The soil temperature is increased in drained soil for the reason that the heat required in the evaporation process on undrained surfaces is utilized in heating the soil to higher temperatures. It requires four times as much heat to raise the temperature of water one degree as it does to raise the temperature of dry soil one degree, while it requires twice as much heat to raise the temperature of water one degree as it does to raise the temperature of soil with 20 per cent moisture one degree. The soil bacteria necessary to plant growth become more active when the temperature of the soil is raised. Thus the increased temperature accelerates the germination of seeds in the spring and the consequent growth of the plant after germination.

The aeration of the soil has already been discussed. The pore space of drained soil is about 25 per cent of its volume, which allows air to penetrate the soil and consequently oxygen in the air to be absorbed by the plants and carbon dioxide given off, the excess of which after dissolving the mineral elements in the soil is carried off in a well drained soil by the percolation of gravitational water. The water table in a well drained soil is always undulating, the depressions being over each of the tile drains. The depressions are not so marked immediately after a large rain but become more pronounced after a few hours or a day of tile action.

The Run-off Coefficient

So far, we have discussed certain elements which should be considered in the design of tile systems, but have not discussed quantities of run-off or carrying capacities.

The run-off for tile is usually measured as is rainfall; that is, the certain depth of water in inches which must be removed in 24 hours from the entire water shed. This amount is usually called the drainage coefficient. In the design of open ditches we must consider the entire run-off, both surface and underground, while in an underground drain we are only considering the gravitational or percolating waters which run off. In most instances this is much less than the total run-off but in the case of flat level ground the run-off in both instances might be the same.

No subject relating to drainage merits more consideration than the drainage coefficient of underdrained soils. Tile drainage systems were formerly employed only in the drainage of fields of limited area, a system with a main 8 inches in diameter being looked upon as a large one. Now districts often require drains of pipe 36 inches in diameter.

The determination of economical size of the main, submain, and laterals of such systems becomes a much more intricate problem. Already I have discussed the conditions in which the soil becomes a reservoir for the water which falls. Water percolates through the drained soil and is discharged much more uniformly than over the surface.

In considering the run-off there are three things which should be considered:

First, the amount and intensity of rainfall for periods of 24 or 48 hours. From the climatological reports published by the weather bureau at Indianapolis, the daily rainfalls for any locality in Indiana can be obtained, since there is a weather bureau station located at practically every county seat. The maximum monthly precipitation is usually a fair indication of large daily storms, but this is not always the case. The question of run-off is one which could be discussed at length. It varies a great deal, according to topography of land, season of year, condition of soil, whether already wet or dry, porosity of soil, and various other features.

If the intensity of rainfall were great, a 1-inch rainfall might have as much as ½-inch run-off if taken over a tract of land with steep slopes and an already saturated soil. However, observations have been made where a 1-inch rainfall produced no run-off at all. In fact, one observation was made where plowed ground absorbed a rainfall falling at the rate of 1 inch per hour for a period of 30 minutes without producing any run-off.

Second, the season of the year may somewhat govern the run-off. If rainfall occurs in the winter or spring months, the run-off is larger than if the same amount of rainfall occurs during the summer months when evaporation and transpiration are great.

Third, the openness of the soil and the resulting rapidity with which it will absorb the rainfall. An open soil will permit the water to reach the drains more rapidly than will a dense clay soil and hence will require tiles of greater capacity but with lines placed farther apart.

The very quick and rapid removal of soil water is not desirable in the drainage of farm land. The object should be to remove the surface water quickly and secure gradual movement of water through the soil into the drains. This movement is beneficial since fertilizing materials at the surface, both solid and gaseous, are lodged with the soil particles as the water percolates among them and the air follows with its disintegrating effect upon the unweathered earth. For this reason, sufficient drainage is better than too much.

Capacity of Tile Drains

The U. S. Department of Agriculture has made considerable investigation of the run-off of various tile systems in Iowa and Illinois in order to determine the capacity of drains. The results of their investigations in Livingston and Iroquois counties, Illinois, are as follows:

System	Diameter of Tile	Grade of Drain Percentage	Acres Drained	Drainage Coefficient
A	24″	.12	1040	.16
B	18″	.07	400	.16
C	15″	.05	400	.08
D	18″	.10	480	.16
E	20″	.09	1020	.114
F	22″	.17	680	.143
G	18″	.05	1280	.053

The soils of these various systems is a black, open loam and readily responds to underdrainage.

Systems A and B consist of level marsh land with sandy subsoil. These systems gave satisfactory results.

System C was much too small.

In System D, the land was somewhat rolling and the tile proved too small to give satisfactory results.

System E gave satisfactory results due to the fact that it comprised a long narrow valley and considerable surface water ran off along a shallow drain over the tile.

System F proved satisfactory.

System G gave fairly satisfactory results but was partially aided by a shallow overflow ditch.

In Boone County, Iowa, similar tests were made on tile systems, ranging in diameter from 12″ to 28″, draining from 150 to 1,240 acres with resulting drainage coefficients of from .14 to .27 inches.

The conclusions reached from these investigations were that, for reasonably rolling or undulating ground, if partially aided by shallow overflow ditches, a drainage coefficient of 1/5 to 1/6 inch, is usually sufficient, while a ¼-inch coefficient will nearly always prove satisfactory. The rainfall for those localities cited above seems to compare favorably with that in Indiana.

After selecting a drainage coefficient in order to select the size of tile to be used, we must know the grade to which the tile is to be laid. This is a very simple matter to obtain by taking levels over the line of location. Then we must ascertain the velocity of flow expected. A number of formulae have been developed for the flow of water in tile drains, all of which give results which vary but little for practical use. Personally, I am partial to the Chezy-Kutter formula because I have made most use of it.

Typical Problem

Suppose it is required to determine the size of the outlet tile to be used to drain a 180-acre farm, the lower 1,000 feet of length having a grade of .2 foot per 100 feet, assuming a drainage coefficient of ¼ inch. The ordinary method to be used is to select approximate size and solve the problem to see whether or not your assumption is correct.

We will assume that a 12″ tile is required; then in Kutter's formula

$$c = \frac{\frac{1.811}{n} + 41.65 + \frac{.00281}{s}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{.00281}{s}\right)}$$

in which n is the coefficient of roughness and s the slope. For tile drains, properly laid, n should be .011.

s in the above equation is .002 per cent.

r is the hydraulic radius or $\frac{a}{p}$.

Solving this equation and substituting the values, we get $c = 106.3$.

Then from Chezy's formula, we have $v = c\sqrt{r\,s}$

$$\text{or } v = 106.3\sqrt{.25 \times .002}$$

$$\text{or } v = 2.36 \text{ feet per second.}$$

Then from the equation $Q = A\,V$

we have $Q = .7854 \times 2.36 = 1.85$ cubic feet per second.

In order that ¼″ of water may be removed from one acre of land in 24 hours it is necessary to discharge .0105 cubic foot per second. Hence 1.85 ÷ .0105 gives 176 acres, which is approximately the result desired. By this same process, the size of the submains and laterals may be determined.

It is not necessary to figure it all out in this way if we have access to a discharge diagram such as found in Bulletin No. 854, U. S. Department of Agriculture. From this one can at once select the velocity, discharge, slope, and even acres drained by all sizes of tile ranging from 4″ to 48″ in diameter, with drainage coefficient ranging from ¼ to 1.

I will not go into detail about the elements to be considered otherwise, such as the selection of the tile which will have the proper strength test, the grading and laying of the tile, the protection of the outlets, the refilling of trenches, the layout of the systems, and the construction details. I take it for granted that you are all more or less familiar with these phases.

THE USE OF CALCIUM CHLORIDE AND OIL AS DUST LAYERS ON STONE AND GRAVEL ROADS

By C. W. McClain, District Engineer, Indiana State Highway Commission, Seymour

Of all the traveling nuisances of modern roads dust probably is deserving of first place. Besides being uncomfortable and expensive, it offers a source of danger that has taken its toll of human life by outright slaughter caused by obscured driving vision, to say nothing of the more insidious suffering caused by respiratory troubles which can be traced directly to dust. Any toleration of dust is due either to callous indifference on the part of those charged with contributing to the comfort of the traveling public or to lack of funds with which to carry on the ever-increasing fight against this evil. I am glad to say that those with whom it has been my lot to work in this task have a keen appreciation of the dust problem confronting them and are doing all within their power to bring relief. Any program of extensive dust laying costs money, a factor always confronting those acting as trustees of highway funds. Public demand is merciless in many instances and runs counter to good financial judgment. The