Subdrainage Storm Flows at Airports

Warren L. Lawton, *Civil Engineer*

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The reason there are so many different variations can be traced to a lack of information on their operations. If the pavement does not fail, the subdrain is assumed to be satisfactory, and then the only interest in the subdrain is to see that it is clean and can flow when needed.

This lack of information prompted the Airport Division of the CAA's Technical Development and Evaluation Center, Indianapolis, to initiate a project to study the subdrainage systems at selected airports to determine: (1) the extent to which existing subdrainage systems are functioning; (2) the reason for ineffectiveness where such a condition exists; and (3) the possible need of subdrainage where not installed. This analysis was to furnish a basis for future designs in similar geographical areas.

Due to a reduction in appropriations, this project was terminated before completion and no report was published by CAA. Considerable useful knowledge was accumulated in the study, however, and a part of it is reported herein.

DESCRIPTION OF AIRPORTS

The airports selected were all municipal airports which were built by CAA during World War II. Table 1 briefly shows the airports studied and some of their characteristics. All of them had been recently sealed except the airport at Norfolk, Nebraska, which did not need sealing. One thing not shown on the table is that the Norfolk airport had rough, rolling sand between the runways. Another is that the airport at Dubuque, Iowa, had some limestone excavation during construction, and the natural springs were piped under the fill before construction started. This was to prevent the springs from damaging the fills.

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The well points used were of two types and varied with different airports. The first ones installed were standard commercial well points with 60-mesh screen soldered around the pipe and with a driving point on the lower end (Fig. 1). The pipe extensions used with the well points were slotted on both sides. They were of such a length as to place the center of the well point 6 feet below the top of the ground. The well points used later were made by slotting or drilling a piece of pipe at points along its length. The wells were vented by a small hole drilled in the caps which were used to close the upper end of the pipes. A

TABLE 1
AIRPORTS STUDIED

Airport	Type of Pavement	Condition of Pavement	Condition of Sod	Location of Site
Cedar Rapids, Iowa	Concrete	Good	Very good	Rolling plains
Burlington, Iowa	Concrete	Good	Very good	Rolling plains
Dubuque Iowa	Concrete	Good	Good	Top of three hills
Mason City, Iowa	Asphalt	Good	Very good	Alongside of flat hill
Terre Haute, Indiana	Asphalt	Good	Good	Rolling plains
Norfolk, Nebraska	Asphalt	Very good	Fair	Foot of 2½ per cent slope

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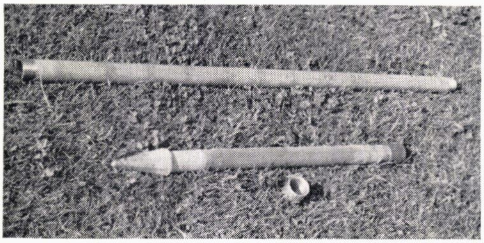

Figure 1. Commercial well point.

plastic tube was placed in the hole to keep the water out.

The well points were installed by drilling a 1½-inch hole in the ground to the depth desired. The commercial well points were larger than the hole and required driving. The second type of well point (made of straight pipe) was smaller than the hole. These points were lowered into position and sand was worked into the space between the pipe and soil. For well points under pavements, pipe was used. To install these, the hole drilled in the ground was slightly smaller than the pipe and required driving.

The water elevation in the well point was read periodically by one of two methods. The first method was to use a 6-foot folding rule, as shown in Figure 2. A broad black stripe was painted along the side of the rule for the first 6 inches. This stripe was powdered with portland cement before each use. Upon touching water, the cement was washed off. When the ruler was removed from the well point, the exact depth to which the end of the rule was submerged was revealed by the clear washed section. The second method was to use a sensitive ohmmeter to determine when two electrical contacts at the end of a rod were just touching the water.

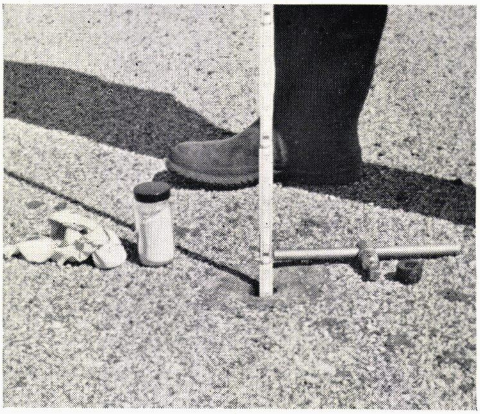

Figure 2. Measuring depth to water in well.

Figure 3. Map cracking in soil.

Map cracking, such as is shown in Figure 3, occurred on most of the airports and permitted surface water to flow into the well points. For this reason it was felt necessary to seal each well point.

Two methods of sealing the well-point pipe at the ground surface were tried. The first was to place a mixture of bentonite and sand between the pipe and soil for a depth of about a foot. The second method was by a specially designed metal cover about a foot in diameter. This was sealed to the pipe with a neoprene gasket. This cover was placed 6 or 8 inches below the ground surface.

FLOW METERS

The flow data were at first obtained by measuring periodically the outfall of each subdrain studied. The rates of flow were computed from the time needed to catch a measured quantity of water in a container. When these proved unsatisfactory, flow meters were designed and installed at selected locations.

At one airport the outfall of the subdrains was sufficiently high to permit conventional equipment to be used. For this, a tank was equipped with four orifices and a flume. This permitted both the low and high flows to be recorded accurately. A water-level recorder was used to make a continuous record of the flows.

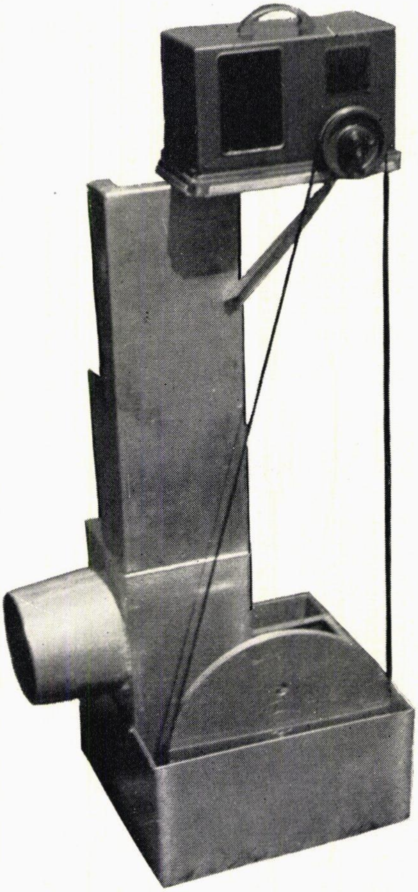

Figure 4. Assembled flow meter.

At the other airports, the flow meter used was designed to work under water and with a very small head loss as the water passed through it. The assembled meter is shown in Figure 4. The two ports were opened by a weighted gate. The farther the gate opened, the larger the ports, thereby permitting more water to flow. The position of the gate was a measure of the water flowing, and it was recorded by a continuous recorder.

ADDITIONAL STUDIES

Moisture samples were taken at the time of installation of well points and additional moisture samples were taken seasonally by borings. Soil temperatures were taken periodically at Terre Haute, Indiana, with specially sealed thermistors. The thermistor leads were brought to a junction box sealed in the asphalt pavement as shown in Figure 5. At each installation one thermistor was placed at each of the following depths: ½, 3, 9, 18, 24, 30, 42, 54, and 66 inches. One installation was made under the center of the runway, one 36 feet from the centerline, one under the edge of the pavement, and one under the sod 10 feet from the pavement. The thermistors were read once a week, and seasonally every hour for a 24-hour period.

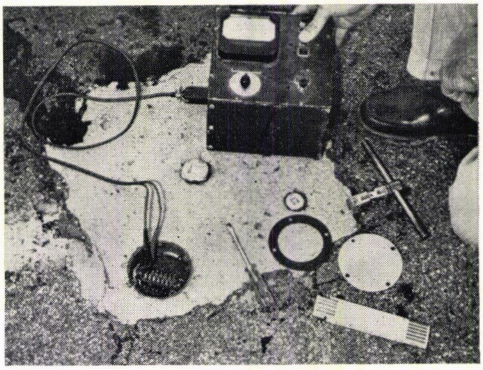

Figure 5. Reading temperatures of ground as revealed by thermistors.

SUBDRAINAGE RESULTS

Well points

It was found that the water in the well points would fluctuate seasonally and with each rainfall. The amount of fluctuation varied with different airports. Figures 6 through 11 show the seasonal variations of three air-

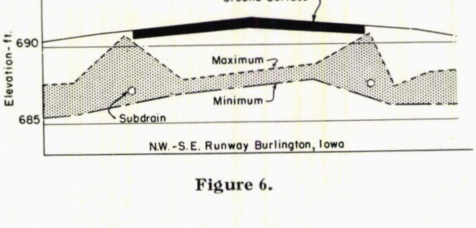

Figure 6.

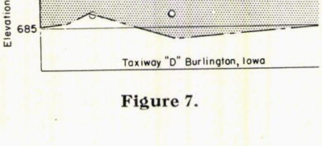

Figure 7.

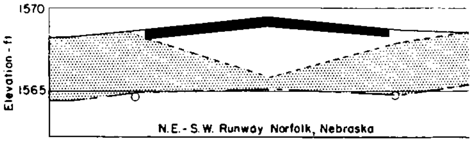

Figure 8.

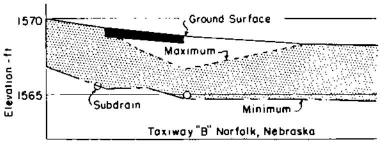

Figure 9.

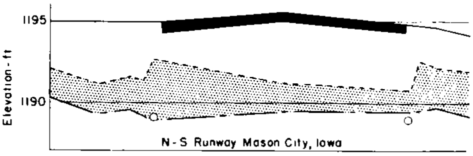

Figure 10.

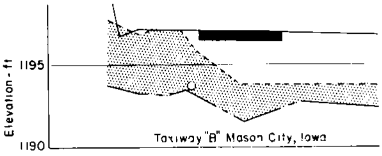

Figure 11.

ports. The results from the other three airports were similar. The bottom line is the minimum recorded ground water elevation. The circles represent the location of the subdrains. The next higher line is the maximum recorded ground-water elevation. The shaded area between these two lines is the amount of fluctuation in the well points. The top line is the ground surface.

Flow Meters

When flow meters were placed in the subdrain lines, definite peaks of flow were recorded for each rain. Figure 12 shows one of these peaks, along with the rainfall which produced it. This happened to be a thunderstorm. Next, the peaks for each rainfall were plotted against the rainfall which produced them. This is shown in Figure 13. Here we find a band of points. The two sides of the band represent a maximum and a minimum rainfall to produce the same flow. Even though the data were limited for some airports, the minimum subdrain-runoff condition was indicated for all airports. When these were plotted for all airports studied, a family of curves was obtained and is shown in Figure 14. Assuming that all of the rainfall is distributed over a period of an hour, it is possible to compute a theoretical width of falling rain equal to the amount of water entering the subdrain. Then the slope of the curve becomes a measure of the efficiency of the rainfall in entering the subdrainage system. Below are listed the

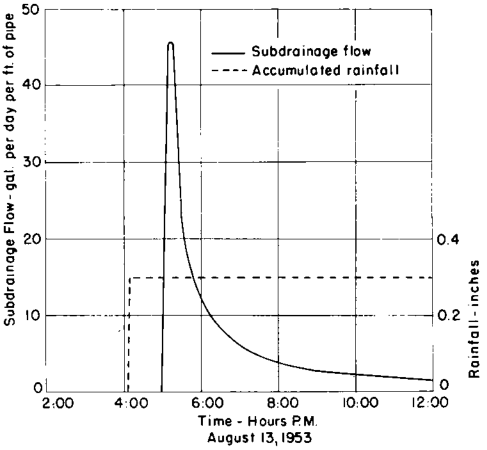

Figure 12. Subdrainage flow from a thunderstorm, Cedar Rapids, Iowa.

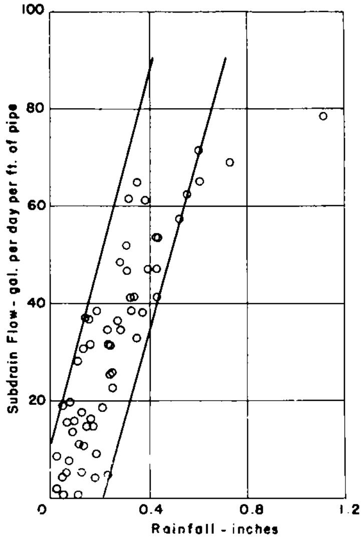

Figure 13. Subdrainage flow, Terre Haute, Indiana.

airports studied in the order of decreasing efficiency indicated and their theoretical widths of rainfall.

Airport	*Theoretical Width*
Terre Haute, Indiana	12.5
Burlington, Iowa	7.3
Dubuque, Iowa	5.3
Norfolk, Nebraska	3.4
Mason City, Iowa	3.0
Cedar Rapids, Iowa	1.7

In order that these airports might be compared further, cross-sections are plotted in Figure 15 and the mechanical analysis of each soil is tabulated in Table 2.

RESULTS OF ADDITIONAL STUDIES

To determine how the soil temperature varied under an asphalt pavement during a period of a year, the 54- and 9-inch depths were plotted in Figure 16. The temperatures of the in-between depths were not different from those shown, and fell between them. The shallower thermistors were not installed until later and their data were incomplete.

In order to show the hourly temperature variations, the same two depths were plotted in Figure 17, but the surface and air temperatures were added. From this study and the soil characteristics, it was possible to determine the amount of heat passing through each layer of soil. This is plotted for selected days of study in Figure 18.

From the moistures taken at different seasons, a variation of moisture with depth is

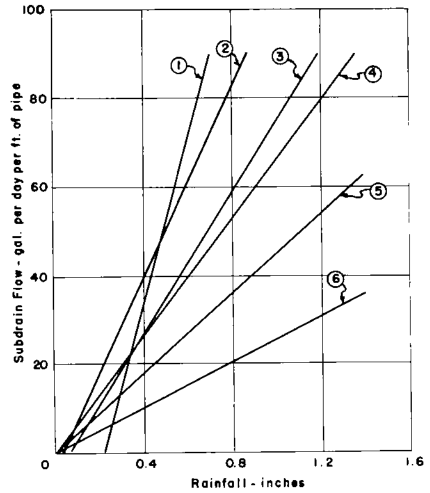

Figure 14. Minimum subdrainage flow at airports: (1) Terre Haute, (2) Burlington, Iowa, (3) Dubuque, Iowa, (4) Norfolk, Nebraska, (5) Mason City, Iowa, and (6) Cedar Rapids.

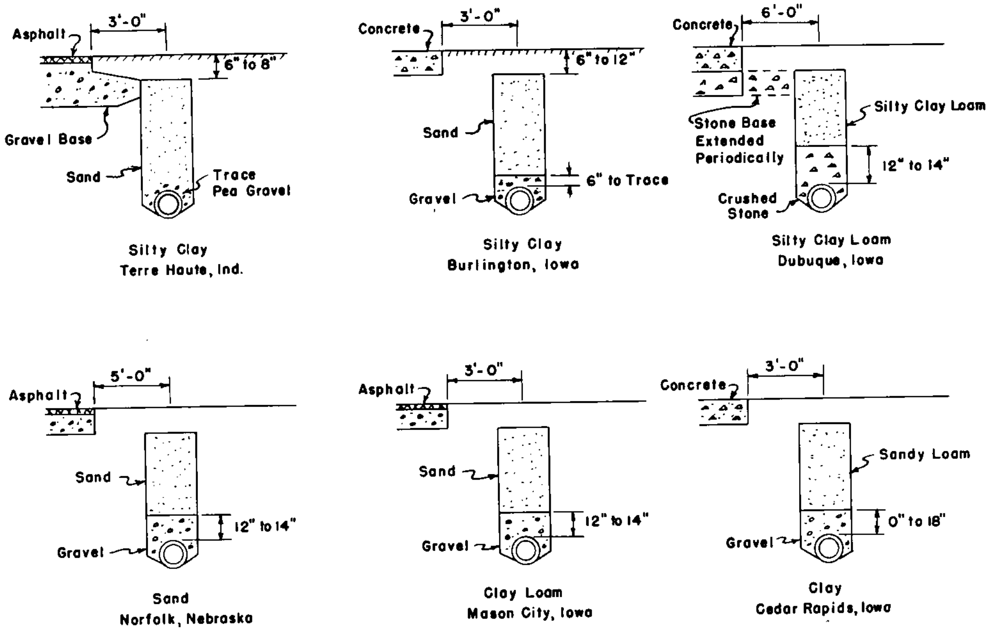

Figure 15.

TABLE 2
MECHANICAL ANALYSIS

Percent Passing Sieve	Airport					
	Terre Haute	Burlington	Dubuque	Norfolk	Mason City	Cedar Rapids
Mechanical Analysis of Subsoil						
1″						
¾″						
⅜″						
#4		100		100	100	100
10	100	96	100	99	97	98
40	99	96	99	93	90	97
200	98	94	98	19	78	93
Percent Sand	9	15	15	94	40	16
Percent Silt	53	50	59	3	35	47
Percent Clay	38	34	26	3	25	37
LL	49	45	38	N.P.	45-37	49
PI	26	25	15	N.P.	18-19	27
Mechanical Analysis of Soil in Trench Above Drain Backfill						
1″						
¾″				100	100	
⅜″	100	100		99	97	
#4	95	82	100	97	94	100
10	80	62	99	90	88	98
40	28	25	96	81	54	92
200	1	3	90	21	8	76
Percent Sand	98	92	20	88	89	76
Percent Silt	1	5	57	6	6	11
Percent Clay	1	3	23	6	5	13
LL	N.P.	N.P.	—	N.P.	N.P.	—
PI	N.P.	N.P.	—	N.P.	N.P.	—
Mechanical Analysis of Drain Backfill						
1½″			100			
1″			97		100	
¾″		100	84	100	99	
⅜″	100	67	62	98	66	100
#4	95	38	54	90	32	47
10	80	27	52	71	29	19
40	28	11	49	30	20	15
200	1	1	43	4	4	10
Percent Sand	98	91	29	97	84	71
Percent Silt	1	6	46	2	8	19
Percent Clay	1	3	25	1	8	10

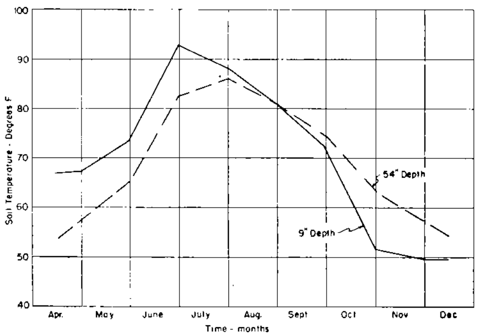

Figure 16. Monthly temperatures at centerline for asphalt pavement at Terre Haute, 1952.

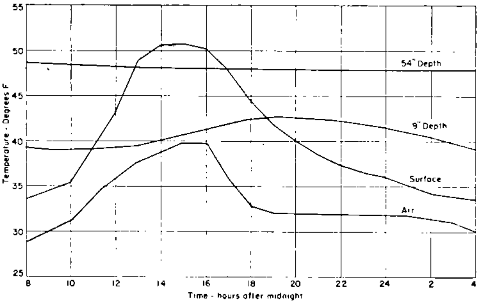

Figure 17. Hourly temperatures at quarter points for asphalt pavement at Terre Haute, February 13, 1953.

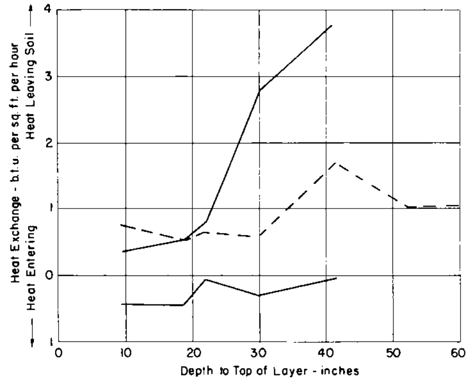

Figure 18. Thermal conductivity of soil.

shown in Figure 19. Each point represents an average of several moisture determinations.

DISCUSSION OF RESULTS

Well Points

The water level in the well points is not always the true ground-water elevation. It is true only when the permeability of the well point and surrounding soil is sufficiently large to permit rapid water-level changes in the well points. For this reason it is advisable to make a series of readings rather close together to see if the well point is following the ground-water table.

It was found that during rains the ground surface and runways were covered with water to a depth of ½ to 2 inches. This water enters any crack or hole in the ground. The data show that for many of the airports the ground water will rise to the surface of the ground during rains.

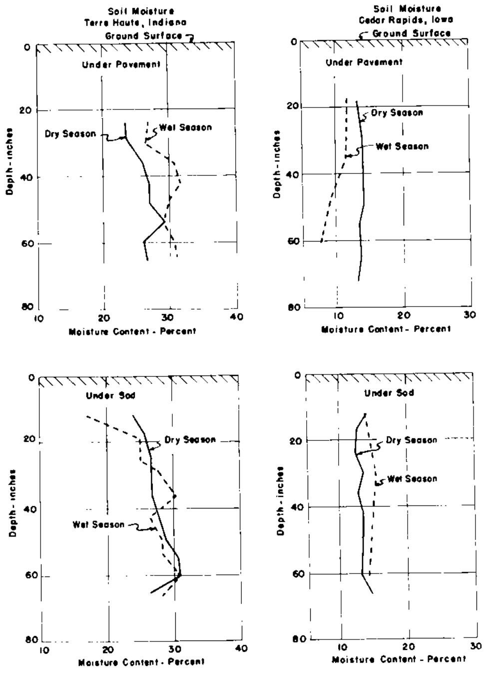

Figure 19.

The map cracking shown in Figure 3 seems to exist on all airports and goes deep enough to allow surface water to enter the subdrains. They also take the water into the well points no matter how well sealed. The cracks seem to be filled with sand and do not seal themselves even during the wet season. The subdrain ditch cuts these cracks and prevents them from carrying water past the subdrain to points under the pavement.

The subdrain tends to lower the water table at the edge of the pavement, but at the same time the water flowing off the pavement concentrates a large amount of water above the subdrains. Under these conditions the ground-water elevation still rises near or to the surface of the ground. Figures 6 through 11 clearly show that the maximum ground water elevation is not lowered by the presence of the subdrain.

The above condition does not last long after the rain stops. Readings taken during and after a rain on several airports showed this to be true. After the rain stops, even an hour means a lot of fall on some of the airports. For some of the airports, no readings were taken during and after a rainfall, and for this reason a complete picture of what happened was not obtained. For these airports, the maximum ground-water elevation might have been higher if read continuously.

Under the condition of maximum ground-water elevation, the surface water leaks through the pavement and ground water leaks past the subdrains. This condition makes a ponded or perched water table directly under the pavement. This was revealed by shallow well points just through the pavement and the other observations on four of the airports studied. Three were concrete and one was asphalt. On the other two airports, no study was made.

The length of time required to remove this perched water is about two weeks and is more than enough time to do harm to the subgrade soil. The reasons it does not are as follows: (1) the base course is designed to spread the load over a sufficiently large area to be carried by the reduced subgrade strength; (2) the weight of the base course material and pavement prevents the soil from swelling and further reducing the soil's bearing strength; and (3) the traffic does not normally produce a destructive type of pounding.

The minimum ground-water elevation was produced under one of two conditions. The first was a long drought which occurred during this study. The other was during the winter when the ground was frozen. Between rains or other precipitations that replenish the ground water, the ground water is continuously falling. The rate of fall is a factor of how fast the water can run away, evaporate, or be used up by plant life. The minimum ground-water elevation then becomes a result of the length of time between replenishments. During the winter, the soil on several of the airports froze and stayed frozen for a long time, even though the ground was covered with snow. This frozen ground stopped the ground water from being replenished, just like a drought.

Flow Meters

When flow meters were placed in the subdrain lines, two different types of flows were noted. The first consisted of definite flow peaks for each rain. This type is plotted in Figure

12. The other type of flow was the result of intercepting ground water flowing out of a hill or high ground near the airport. The subdrain design for either flow should be the same. The only difference might be in the depth or location of the drain in order to perform each type of work best.

For the flow produced by rainfall, the time interval between rainfall and start of flow is a little less than an hour for all airports. After the flow starts, it rises rapidly to a peak and remains there as long as the rain is steady. When the rain stops, the flow decays, following a logarithmic-type curve. The shape of the curve depends upon the storage capacity and drainage characteristics of the system. Whenever a rain occurs before the decay is completed, a new peak is formed and another decay cycle starts.

When the peak flows are plotted against the rainfall which produced them, a band of points is obtained. One side is a maximum and the other is a minimum. At some point near the top of the flow value, the water flowing through the ground reaches a maximum water-carrying capacity and additional rain does not cause additional flow. There are several points on Figure 13 which show this condition. The slope of the minimum flow line is a measure of the efficiency of the rain getting into the subdrain. This line was extended above the point of top flow in order to obtain a more accurate slope value.

The above-indicated efficiency of the different drains revealed that some of the designs are better than others. The most-efficient and the least-efficient subdrains are in parent material almost identical in characteristics. The efficiency of the subdrainage system in these cases is entirely due to the backfill material above the subdrain. For the most-efficient subdrain, the backfill was a concrete sand. All passed the ⅜-inch sieve, and 99 percent was retained on the No. 200 sieve. This material was used to backfill to within 6 or 8 inches of the top of the ground. It should be noted that this material did not silt up, even though it was in contact with the smallest-grained soil in the study. However, there was not enough coarse material around the pipe and the backfill material did wash into the pipe until the pipe was about a third full.

For the other airports, the efficiency decreased as the porosity of the backfill was decreased, and the thickness of cover over the backfill material was increased.

At Dubuque, Iowa, the backfill was made too porous and the soil washed into it until the overall material was no different from the surrounding parent soil.

At Cedar Rapids, Iowa, the porous material was deep and there was only a little around the pipe. This design was of the lowest efficiency. The theoretical width of rainfall for this design was less than the width of the ditch used to install the subdrain.

It should be mentioned that at Terre Haute, Indiana, the flow in the 6-inch subdrain often filled the pipe and had a head of water behind it. This was revealed by a water-level recorder in a manhole part way along the subdrain. This flow was about a tenth of that shown in hydraulic tables for this pipe at the installed slope. This is probably due to the turbulent effect of the water entering at each joint.

Additional Studies

The temperature study showed that the ground temperature had daily cycles as well as yearly cycles. It showed that the temperature changes under the asphalt pavement were greater than those under the sod. It showed that the asphalt pavement and the soil immediately under it was warmer than the air temperature for normal conditions. It also showed that during the summer the soil near the top of the ground was warmer than the deeper depths, and in the winter it was reversed.

From the heat study, it was found that it was possible to have more heat entering a layer than was leaving it. This condition can exist when water is evaporating in the soil layer. However, at the maximum rate shown, the soil moisture was changing at a rate of 1 percent of moisture per week.

The moisture study showed that the seasonal change in subsoil moisture was about 1 percent. (The study did not include the first 6 inches of topsoil or the Norfolk Airport.) The greatest difference in moisture content was caused by variations in gradation. Samples taken at the same time and often close together frequently had a large difference in moisture content in spite of their being taken at the same elevation. These differences usually were larger than the seasonal change. It was only by averaging a large number of samples that the true picture was revealed. Samples taken under the pavement were found to have the same moisture content as samples taken under the sod.

CONCLUSIONS

The subdrainage system does keep the ground-water table (except for the perched water under the pavement) down to a low elevation under the pavement. The well points under the pavement that did not show this result were not functioning correctly. A study of their action before, during, and after a rain indicated that they were leaking water from the perched water table and were at the same elevation as the shallow wells part of the time. At some places (Dubuque, Iowa) the well-point pipes were known to have holes connecting them directly to the perched water table.

The subdrainage system does carry off a large amount of surface water that would otherwise have to flow a long distance across the soil surface to a catch basin. The water runs to each side of the pavement during a rain and concentrates a large amount of water on the 20 feet of sod on each side of the pavement. This is reflected by the type of runoff from the subdrain and the high ground-water elevation in the wells in this area.

The subdrainage system does not keep the water off the subgrade soil directly under the pavement. This water remains in contact with the subgrade material long enough to be harmful to the subsoil.

The subdrainage system does not affect the moisture content of the (1) silty-clay, (2) clay-silt, or (3) silty-sand types of soil. The seasonal moisture content is the same under the pavement as under the sod. The seasonal moisture content change is about 1 percent by weight.

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