

A REPORT OF THE COMMITTEE ON SUBSURFACE DRAINAGE

PRESENT PRACTICE IN SUBSURFACE DRAINAGE FOR HIGHWAYS AND AIRPORTS

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SYNOPSIS

This paper is a tabulation of replies to a questionnaire prepared by the Committee on Subsurface Drainage, Highway Research Board.

Nearly all replies stated that faulty subsurface drainage caused pavement failures, including rutting and shoving in flexible pavements, pumping in concrete pavements and frost heaves and boils in both types of pavement.

Practically all replies gave clogging of backfill material, and sometimes pipe, as the chief cause of subsurface drainage failures. Under improvements since 1942, practically all replies noted improved backfill material; their specifications now call for concrete sand, clean bank-run sand, or bank-run gravel (or the equivalent) for backfill with occasionally $\frac{1}{2}$ - or $1\frac{1}{4}$ -in. stone given as an alternate. About half the organizations use either a filter test or the Vicksburg piping ratio criterion for filter design; the others make no test. The almost unanimous use of clean, sandy backfill is in marked contrast to the earlier practice where three-fourths of the states used stone or screened gravel. Practically all organizations use perforated metal pipe and tile pipe; some also use concrete pipe.

As would be expected, the chief use of underdrain instead of deep ditches occurs where the latter would be a traffic hazard.

Depth of pipe invert or deep ditch varies between 2 and 6 ft.; usually it is about 2 ft. deeper than the average frost penetration under a bare pavement. About two-thirds of the states report that subbase is carried out to full width of shoulders; the balance replied that it is carried only to 1 or 2 ft. beyond edge of pavement. Total thickness of surface, base, and subbase varies widely, of course, with conditions of frost, soil, traffic, etc. and is from 6 to 32 in. thick.

The replies on sand drainage wells show that four state highway departments have used them; replies from federal agencies included mention of them on about four dams or dikes and three airports. In each case the results were favorable.

Questionnaires were sent to the highway departments of all states, to the division offices of the U.S. Bureau of Public Roads, the U.S. Corps of Engineers, Department of the Army, the U.S. Civil Aeronautics Administration and the U.S. Bureau of Reclamation. About 90 percent of these organizations replied. A list of the 38 questions and a tabulation of all replies will be found in Tables A, B, and C.

While most questions pertained to present practice, some dealt with related matters, such as failures of subsurface drainage and their effect on the pavement, width and depth of subbase, depth of frost, vertical sand drainage wells, improvements in practice since the 1942 questionnaire on this subject (1) and research.

As all subsurface water originates from precipitation of rain and snow, a map of the county (Fig. 1) with precipitation contours (2) is of interest. Judging from the replies, however, the amount of annual precipitation does not greatly govern the amount of subsurface drainage problems. An exception to this is found in a few of our most arid states, such as North Dakota and Nevada, which report that subsurface drainage is not greatly needed because of the dry climate.

For convenience in classifying the replies, the country was divided between the shaded area and the white area shown in Figure 1. This division coincides approximately with the 40-in. precipitation contour and with the general soil types, based on a pedological classification. Soils in the eastern and southern states (white area on map) are largely the more leached podzols and brown, gray-brown, red, and yellow podzolic soils. In the western areas prairie soils, chernozems, chestnut soils, brown soils and the various desert soils predominate.

On the basis of soil origin, the areas are somewhat less distinct. However, a map of the origin of United States soils (3) classes nearly one-third of the western states as being in non-soil areas while a much smaller non-soil area is found in the eastern section. Both sections have large areas of residual soils. While both also have glacial and coastal plain soils, the largest areas of glacial soils are in the

western states and coastal plain soils in the eastern section.

Geologically, there is perhaps no good basis for distinguishing one area from the other, although the difference in practice between individual states in each area may be striking and might offer an interesting approach to a comparison of subdrainage practice.

The questionnaire submitted to the various states was divided into eight general headings which have been followed in this analysis of replies. In general, the replies are as much remarkable for their diversity as for any tendency to show trends or the development of standard practice throughout the country. This apparent lack of standardization in subdrainage practice in the different states is a reflection of the widely varied subsurface water conditions encountered and, to a lesser degree, of the usual variations in personnel and organization. A definite trend toward standardization in the matter of gradation of the backfill aggregate is found.

Failures caused by subdrains. (Questions 2 and 20) - The seriousness of faulty subsurface drainage was recognized by nearly all states, although no attempt was made to obtain quantitative data on the cost of poor subdrainage, such as was done in 1942. Most replies agreed in substance with those of Minnesota and Wisconsin, which stated that the majority of pavement failures are due, either directly or indirectly to excessive subgrade moisture. Only North Dakota and the South Pacific Division of the Corps of Engineers reported no troubles from faulty or inadequate subdrainage. North Dakota qualified this statement by pointing out that the nature of her problems were such that the practice of careful soil selection and the use of additional base and subbase thickness was generally followed in place of subdrainage. It is interesting to note also that this state has a semi-arid climate and reports no rock cuts. Nevada and New Mexico indicated that their subsurface water problems were not severe.

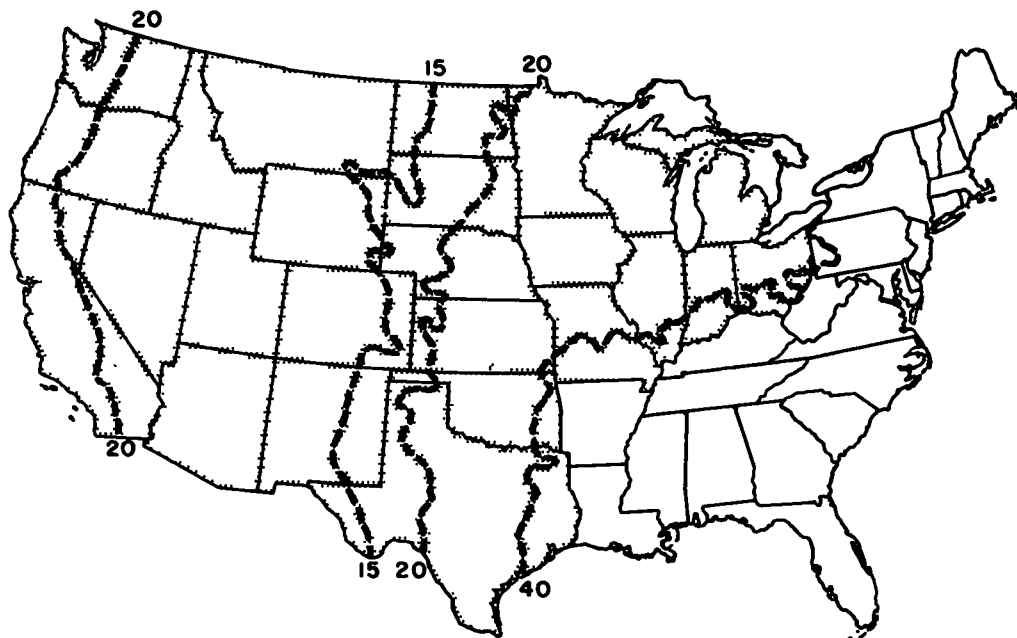
The types of failures attributed to poor subdrainage include almost every type common to either flexible or rigid surfaces.

Of the 54 replies, 45 listed loss of subgrade bearing capacity as a principal result of faulty subsurface drainage. Frost heaving and subgrade softening due to the accumulation of water by frost action were mentioned in 24 replies, inasmuch as those states have relatively deep frost penetration, at least in their mountainous areas. Several states (Maine, Massachusetts, Michigan, Minnesota, New Hampshire, North Dakota, Oregon, South Dakota, Vermont, Wisconsin, Wyoming, Washington, and Bureau of Public Roads Divisions Five (North), Eight, Nine, and Ten) reported depth of frost of 5 to 8 ft. While more states mentioned damage to bituminous surfaces and flexible pavements, the number and variety of failures of concrete pavement listed show clearly that subgrade moisture conditions usually are equally important to either type of surface. Arizona, however, reports that they do not use subdrainage adjacent to concrete pavement. Pumping of concrete

pavements was listed in eight replies, and one mention was made of deterioration of concrete as resulting from subsurface water conditions. It is not clear whether a direct or indirect effect was implied. However, there seems to be some minor evidence of a relationship between deterioration (d-cracking) in portland cement concrete and the occurrence of subsurface water in the subgrade; more studies similar to those made by the Bureau of Public Roads (4) a few years ago on the chemicals of the soil solution may develop some useful information on this common disease of concrete.

Kansas, Kentucky, and the Eastern Park and Forest Division of the BPR reported failures due to landslides which were caused by lack of underdrainage. The CAA reported settlements due to movements of foundation soil into the underdrain backfill.

What criteria are used in establishing the need for subdrains and when are additional



----- ANNUAL PRECIPITATION IN INCHES

Figure 1. Contours of Precipitation in the United States. The white states have more than 40 in. annual precipitation.

base thickness or deep ditches used in place of drains? (Questions 3, 4, 5, and 6.) - The replies to the question, "What criteria do you use in determining if subsurface drainage will help stabilize the subgrade?" at first seem remarkable for their diversity. However, it must be realized that while the questionnaire deals with subdrainage as a general topic, the replies often have in mind the particular type of subdrainage (interception, drawdown, base and subbase de-watering drains, etc.) with which the particular state is most usually concerned. Thus several replies, 22 in all, stress the permeability and gradation of the soil as of prime importance in determining the need for subdrains. Other replies listed the depth to the water table as a first consideration. South Dakota and a few other states listed the presence of pervious layers overlying impervious material as a major point to be considered. Obviously, these states have many subsurface water problems which can best be dealt with by interception subdrainage. Texas and Kansas pointed out that the need for subdrainage can be predicted from a knowledge of the geology of the area and of the type of material in the subgrade.

In this connection it can be noted that the use of geology is becoming more recognized, and today a number of highway departments have full-time geologists on their staffs (5). Utah notes a need for subdrainage as a result of the construction of irrigation canals near the roadway. Illinois reports the use of snow and rainfall data in determining the need for subdrainage. It is assumed that the type of subdrainage referred to in this case is base and subbase de-watering drains.

The apparent diversity of criteria used in establishing the need for subdrains points to the need for a standard nomenclature for drains. The analyses of answers to many of the questions was difficult and uncertain, because the statements made did not apply to similar conditions. For example, where a drain is intended to lower the water table, it is entirely possible that several standard depths, varying with the soil type, may be established successfully. McClelland's charts (6) may be useful in this. However, where the in-

tent of the drain is to intercept the flow of water in a narrowly confined zone in either the soil or bedrock, there can, of course, be no thought of a standard depth.

Some states report that most of their subdrain installations are the result of the uncovering of seeping water during construction or of a failure of the road under traffic. The encouraging trend, however, is to use the soil or geological survey in locating drains in advance of construction. There were indications that this practice may lead to the installation of necessary underdrains at locations where no water was discovered due to dry weather, either during the subdrainage study or the construction. This clearly indicates a growing use of a fundamental knowledge of subsurface water.

Nearly every state indicated that additional base or subbase is sometimes substituted for subsurface drainage in soils of high capillarity. Although the question did not ask it, probably these states use both subdrainage and additional subbase in certain cases. North Dakota (as previously mentioned) and Nevada report that good, cheap aggregate was widely enough distributed in the state to make possible short hauls. Thus it is cheaper for them to thicken the base than to install subdrains. New Mexico, on the other hand, reports, "In those cases we have had to deal with, it was cheaper to trench and use perforated pipe (ie., than to thicken the base)." Division Nine of the Bureau of Public Roads states that the thickening of bases and subbases is used because its experience has never given full confidence in the results obtained with any subdrainage system. Kansas expresses the opposite view in stating that the use of thicker bases and subbases has been generally unsatisfactory as a substitute for subdrainage. Illinois, Ohio, Vermont, Connecticut, and the CAA report the two methods are often used in combination. In general the decision of which method to use seems to be based on relative cost and on the drainability of the soil as determined by the soil survey.

In reply to the question "When do you use an underdrain instead of a deep ditch?" the principal objections to the ditch were the traffic hazard, cost and other con-

siderations in obtaining right-of-way, and the danger of erosion with deep ditches. Seven states never use ditches. Most replies, however, indicated that deep ditches were used when the three factors listed above were not major considerations. Several replies stated some preference for the ditch over subdrainage and one state (Minnesota) does most of its drainage by open ditch.

Of the 54 replies, 19 report the use of a single pipe to carry both surface and subsurface water, but 14 of these replies stated that this practice was used only in exceptional cases.

Types and Causes of Failures in Subsurface Drains. (Question 1.) - The types of failures of subsurface drains listed in these replies are, in order of number of times mentioned:

(1) Silting of backfill. 33 replies listed this type of failure. This is generally attributed to too open a backfill material. Replies did not indicate whether failures of this type were continuing with the present trend toward finer, dense graded aggregate.

(2) Broken pipe. This was mentioned in twelve replies. Shifting of the alignment of pipe and settling are included in this category. Oregon, Washington and Eastern Park and Forest Roads BPR report pipe broken by landslides. Construction equipment and excess tamping were also blamed for breaks, as was heavy wheel-loads on airports.

(3) Poor maintenance of outlets. (In ten replies.) Weed growth over the outlet promotes clogging or surface wash may stop the outlets. Some reported damage to outlets by maintenance equipment.

(4) Clogging of pipe by roots, insufficient grade, or unspecified cause.

(5) Poor location, including insufficient depth.

(6) Poor construction practice.

(7) Freezing of the pipe at the outlet.

(8) Clogging of pipe by small animals or their nests. Clogging of the outlet by nests has occurred even where bars were installed over the outlet.

The last five types were each mentioned about three times but undoubtedly their

occurrence is more widespread. As they are less usual types of failures, many replies probably failed to mention them.

Improvement in Practice since 1942 and Present Field and Laboratory Research in Subsurface Drainage. (Question 9, 8, 7) - The most frequently mentioned improvement in practice since the 1942 questionnaire has been in the improved grading of backfill material. This was mentioned in 30 of 52 replies. Figure 2 gives for those states reporting in 1942 (1) a comparison between 1942 practice and present practice in this respect. The solid-black bars represent the gradation used today, while the open bars represent the 1942 gradations. The first bar at the top of the figure represents the gradation given by the Vicksburg tests. Note the trend toward finer aggregate and dense gradations. This is, of course, in line with the Vicksburg results (7).

Nine states report marked improvement in performance as a result of better and more complete investigations of subsurface water conditions. Three states, Oklahoma, Pennsylvania, and Wisconsin, have advanced in the better use of subdrains with bases and subbases. Better marking of the outlets has given better maintenance in Illinois. Texas and New Hampshire report past trouble with broken and misaligned pipe and now report improvement from the use of corrugated-metal pipe. Some of Oregon's difficult slide problems have been helped by using a horizontal auger in placing 6-in. concrete drain pipe. Two agencies report improvement by discontinuing the installation of French drains.

While a wide appreciation and use of the various papers previously published in the Highway Research Board *Proceedings* on subsurface water and subdrainage were indicated, the amount of active research now going forward in this field is rather disappointing. Only a few states even mentioned field observations of results of their subdrainage installations. However, the practice is probably more general than indicated. Illinois is testing the effect on capillary moisture of drains designed to allow the circulation of air. Laboratory studies of clay mineral-moisture re-

relationships are reported by Kansas. The electrical resistance method of measuring subgrade moisture is under investigation in Missouri. Oregon, Utah, and New Hampshire are studying subdrainage in relation to permeability and other soil indicies. Wisconsin has already published the results of some previous research (8). Connecticut will continue research on filter tests, variation of frost heave with depth of water table, and effect on heave of concrete sand backfill compared with coarser backfill (9). Maryland is conducting research on porous-concrete pipe for sand-drainage wells (10).

The Bureau of Reclamation reports the completion in 1947 of a comprehensive program on protective filters for hydraulic and static structures, and the Ohio River Division of the Army Engineers is making airfield pavement evaluation studies which include an analysis of the existing drainage systems and their performance. The New England Division of the Army Engineers made extensive and comprehensive field and laboratory experiments on drainage of sub-base courses in 1945-46 (11), (12).

Type and Location of Pipe or Ditch (Questions 11 to 22) - Very little standardization is to be found in type or size of pipe, installation, depth of drain, or location of trench. There is, however, rather complete agreement among all agencies that perforations should be installed down unless the pipe is used in the outlet section. Since they also state that size and spacing of perforations conform to the latest AASHO specifications, their pipes have perforations below the middle and a 90-deg. arc of solid invert. Only nine (Maine, Massachusetts, Connecticut, Missouri, North Dakota, Oklahoma, Oregon, the Los Angeles District, Corps of Engineers, and the CAA) install the perforations up and then usually only for special situations. All except three agencies report that size and spacing of holes conform to the latest AASHO recommendations.

Perforated corrugated-metal pipe is the most generally used type. Ten agencies listed only this type. Most states and federal agencies allow the use of several different types of pipes. Next to cor-

rugated-metal pipe, open-joint tile is most frequently used. It is followed in order of popularity by open-joint reinforced concrete, perforated tile, clay skip, and porous-wall concrete pipe.

Most states using open-joint pipe require that the joint be covered by either burlap or tarpaper, although some use sections of broken tile or require mortaring one half of the joint. Ohio uses only sealed joints if within 25 ft. of trees. Bell and spigot pipe is, of course, generally specified to be laid with the bell upstream. Some agencies, especially the Army Engineers, require wedging and shimming of open-joint pipe to insure accurate alignment.

While the most common size of pipe used is 6-in. diameter with 8-in. pipe next in popularity, every size from 4 to 24 in. was reported. Most agencies allow a variation to fit different soil and ground-water conditions.

There is little standardization of the horizontal distance of either a ditch or underdrain from the edge of the pavement, and there has been a healthy trend away from standardization of depth of drain. Twenty-four reporting agencies place their subdrains at or very near the pavement edge. However, others place them any place between centerline of the road and the toe of the backslope. Most common location seems to be either near the pavement edge or the edge of the shoulder. Deep ditches are placed at any distance from 8 to 75 ft. from the pavement edge, and there appears to be no mean or normal distance. The need for berms for traffic safety was mentioned in some replies. In airport construction practice, subdrains are generally placed at the pavement edge, but in some cases are reported at distances of 75 ft. from the pavement edge. Deep ditches are, of course, kept a considerable distance from runways; distances of 100 to 400 ft. were reported.

The usual depth of pipe invert or bottom of ditch below the pavement surface varied from 2 to 7 ft; 4 to 5 ft. is about average. This undoubtedly represents an increase in depth over the 1942 practice in many cases. Nearly every state reported a variable depth, the depth generally changing with the type of soil, the depth to the water

table, the depth of frost penetration, and for interception drains, the depth of the impervious layer below the aquifer. Sub-drains for airports are generally drawdown types and more frequently use a standard depth, varying to meet difficult outlet conditions or to obtain a self-cleansing gradient or to avoid crushing the pipe under wheel loads.

Obtaining an adequate outlet is not a serious problem in most states, although several of the states in the glaciated area and the plains states report this to be an occasional difficulty. The Bureau of Reclamation reports that in underdrains for some canal linings it is necessary to pump the water from the drains. The problem of the plugged outlet is, however, rather widespread. The principal points stressed in this respect were the need for obtaining outlets which require a minimum of maintenance and the need for a definite outlet maintenance program. This requires positive marking of all outlets so they will be constantly brought to the maintenance man's attention. No information was obtained on the number of states using headwalls on outlets or the types of headwalls used. However, these were mentioned as an aid in reducing maintenance.

Backfill Specifications and Placement (Questions 23 to 30) - The most significant feature of the gradation of backfill materials is shown in Figure 2, which compares the 1942 and present gradations of various states. Table C shows the gradations used today by nearly all states. It can be noted that while the trend has been to dense, finer gradation, alternate specifications for several states still permit coarse, open gradings. While 29 of the 54 reporting agencies use essentially the same gradation for all type soils, many states list alternate gradations which may, in some cases, as in Kansas, reflect local availability of materials or may indicate the use of a coarser gradation over joints and perforations. Seven agencies provide for special gradations to meet special conditions but indicate that special cases are rare. Ten agencies check the design of backfill material against each soil encountered. In general, there seems to be

less emphasis on special gradations and two-layered gradations than in 1942, probably because perforations are nearly always down. Since the trend has been to use a gradation approaching the general type recommended in the Vicksburg experiments, support is given to the adequacy of those experiments.

Ten states and six federal agencies regularly make tests either of the permeability of the backfill or calculate piping ratios to determine the gradation of backfill aggregate to be used. Most states, however, have concluded that material agreeing in gradation with the Vicksburg tests is useable for most of their soils and do not make tests at each location.

Sixteen agencies usually use coarser material at perforations and open joints. Illinois and Indiana follow this practice in special cases. This two-layer system requires some hand placing. Missouri, and occasionally Connecticut, uses a three-layer system, with finely graded material in the bottom of the trench followed by coarser material around the pipe or over the perforations, if they are up, and in turn by finer material above the pipe. Alabama and the Civil Aeronautics Administration sometimes use a three-layer system with stone around the pipe and sand adjacent to the trench walls. The stone and sand are kept separate when placing by vertical sliding forms.

Rolling and tamping of the backfill was specified by 38 of the states and federal agencies, although some states believe that because of the granular nature of the material, little advantage is gained through tamping. Nearly the same division of opinion exists as to whether impervious soil should be used to backfill the top portion of the underdrain trench. Thirty-five replies said yes; 18 said no. Nevada and Division seven of the Bureau of Public Roads often use grouting or a cement mortar seal to accomplish the purpose. New Mexico specifies a tight A-7 soil for this top layer. Kansas, and probably some other states, does not use this upper impervious layer if the trench is under the pavement but does if it is not covered by the pavement or base course. Several states (Indiana, Kansas, Missouri) and the Bureau of

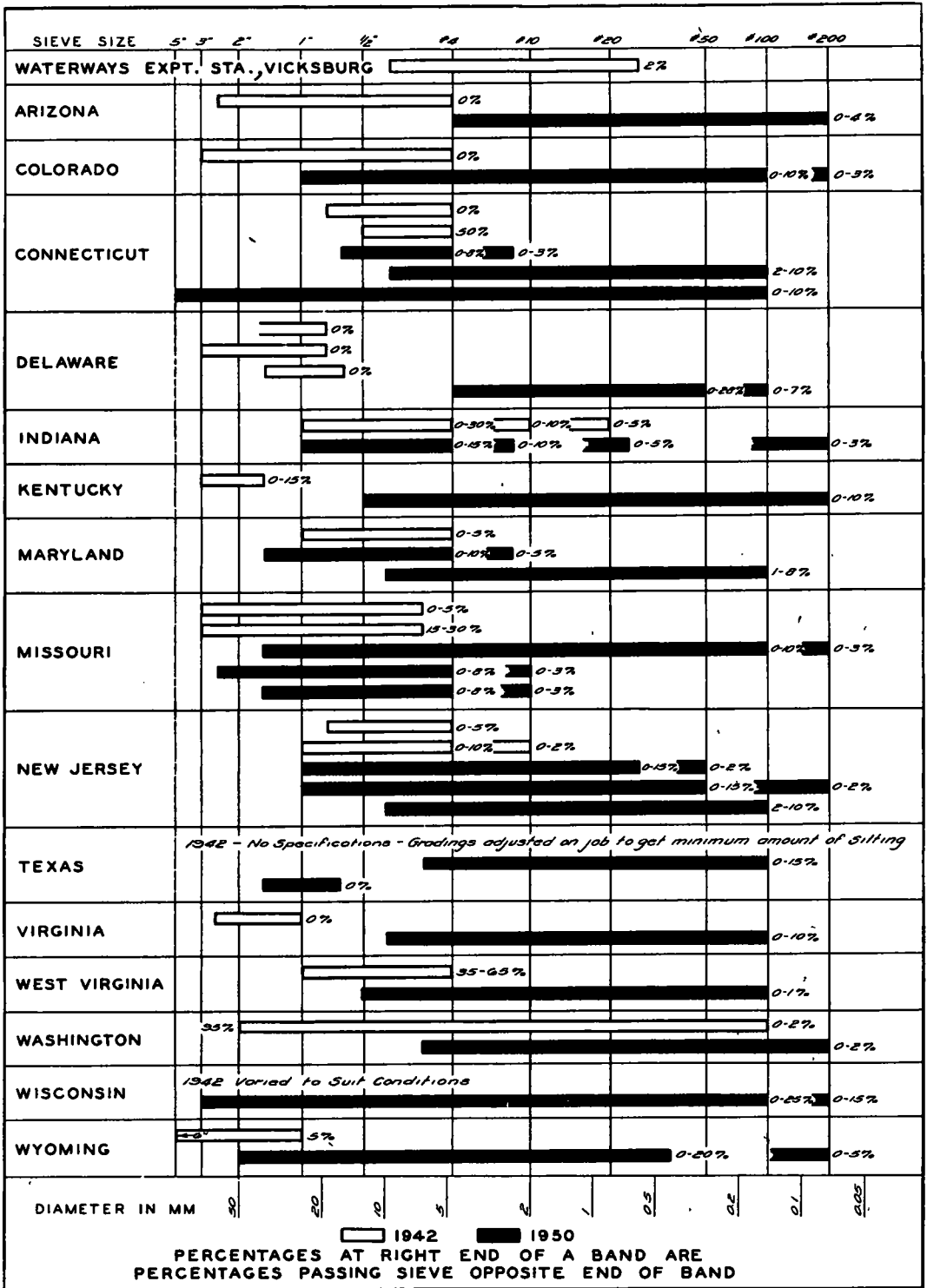


Figure 2. Gradation of Backfill Materials in 1942 and 1950. See Table C for Details of 1950 Gradation.

Reclamation include a clause in their specifications requiring that the backfill be removed and cleaned if clogged by soil washed into the trench by rains. Most answers did not indicate this to be a problem.

Most states use a trench pay-width of about the pipe diameter plus 8 to 16 in. or about 2 ft.; however, the range is from D+6 in. to D+30 in. Utah pays for back-filling widths up to 36 in. for 6-in. pipe. Actual widths may be greater than these pay-widths, depending on the method of trench excavation.

Previous Fill Under Pavement (Questions 31, 32, 33) - Standard practice for 21 of the states is to extend the granular subbase for full width of shoulders. Michigan even specifies from ditch bottom to ditch bottom. Connecticut, Texas, and Utah extend the subbase beyond the shoulder to the side slopes. Indiana and Missouri use full width subbases with open-graded granular material but extend densely graded subbases only 1 ft. beyond the pavement edge.

Division Five (North) of the BPR uses a shoulder-to-shoulder subbase for bituminous construction but extends it only 1 ft. beyond the edge of concrete pavement. Illinois, Kansas, Minnesota, and Ohio use as a standard the width of the pavement plus a minimum of 1 or 2 ft., but like several states, Ohio says that this distance is "generally to porous backfill of underdrain, 2 ft. from pavement." Standard procedure in airport construction as reported by the Corps of Engineers is to extend the granular material to a distance of from 3 to 5 ft. beyond the pavement.

Bleeders to provide drainage for granular subbases are in little favor. Except for seven states, all replies state that the subbase is carried out continuously to the underdrain trench or ditch.

The variation in the total thickness of pavement courses plus subbase in earth and rock cuts in the various states is quite large and not very revealing. Probably some correlation could be found between this thickness and other factors such as soil type, frost penetration, climate, or traffic. Such a correlation is probably complex and certainly not evident from the available figures. One interesting relationship between pavement thickness and

the geology of a state seems to exist, although the figures are not conclusive. Western states which have large areas of relatively flat-lying sedimentary rocks often use a greater total thickness of base and subbase in rock cuts than in earth cuts, while those states largely underlain by massive igneous and metamorphic rocks often use the thicker subbase in earth cuts. It is suggested that this difference in practice may result from the differences in subsurface moisture conditions associated with the two types of rock.

Vertical Sand Drainage Wells (Questions 34 to 38) - California, Connecticut, New Jersey, Missouri, Washington, the Bureau of Reclamation, the Army Engineers, and the CAA report the use of vertical sand drains. Their use was reported by California, Oregon, and Wisconsin in 1942. Missouri reports their use some 25 years ago in swamp areas, apparently for the purpose of draining swamp water into an underground permeable zone, but the other agencies are reporting recent installations for pressure relief in hastening fill settlement. All agencies report beneficial results.

California reports very rapid settlement of the fill with this method--up to 15 ft. of settlement during construction with negligible settlement after construction. Washington obtained rapid settlement and was enabled to complete construction of final pavement immediately. Connecticut has completed three projects and reports settlements to be 10 or 15 times as rapid as without the wells; savings varied from \$15,000 to \$90,000 per project, on projects ranging from small sections of town-aid road to 1,000 ft. sections of expressways. New Jersey's projects are numerous but not completed. The Army Engineers reported their use under dikes; on a dam project the wells saved \$100,000 and several months' time. The CAA reported their use in two regions; on one, airport settlements in a large experimental area were slightly more rapid when the wells were 8 and 11 ft. on centers than when 14 ft. on centers. The compressible material was soft organic silt, 60 ft. thick. The application of soil mechanics using undisturbed samples is recommended as essential by all those who have had experience with the method.

TABLE A

QUESTIONNAIRE ON PRESENT PRACTICE IN SUBSURFACE DRAINAGE

This questionnaire is sponsored by the Committee on Subsurface Drainage, Department of Soils Investigations, Highway Research Board. It is intended to record the present practice and also the progress since the earlier questionnaire on this subject, reported by Levi Muir in the 1942 Proceedings of the Highway Research Board. Referring briefly to the latter may be helpful when answering the questions below. Note that the questions deal with new construction and also with new installations for maintenance purposes. Sketches with adequate dimensions are very desirable. Remarks regarding the adequacy or inadequacy of old practices are welcome, of course, particularly where they illustrate the benefits of progress in subsurface drainage.

GENERAL

1. What types of failures in subsurface drains have you had; what are their causes?
2. What types of pavement failures due to inadequate or faulty subsurface drains have you had; what are their causes?
3. What criteria do you use in determining if subsurface drainage will help stabilize the subgrade?
4. Is additional base or subbase substituted for subsurface drainage in soils of high capillarity?
5. Is a single pipe used to carry both surface and subsurface water? If so, is bottom half of pipe sealed?
6. When do you use an underdrain instead of a deep ditch?
7. Are you conscious of using the information contained in various articles in H.R.B. Proceedings, such as: Porter, Vertical Sand Drains (1938); Russell and Spangler, Energy Concept (1941), Muir, Present Practice in Drainage (1942); McClelland, Large Scale Model Studies (1943); Izzard, Rational Approach (1944); McClelland and Gregg, Methods of Analysis (1944); Keene, Underdrain Practice (1944); Spangler, Subgrade Moisture Control (1945); Lane and Washburn, Capillarity Tests (1946); Krynine, Capillary Flow (1946).
8. What type, if any, of field or laboratory research in subsurface drainage are you conducting?
9. In what respects has your underdrain practice improved since the 1942 questionnaire? (Reported by Muir in 1942 H.R.B. Proceedings).

10. (On new construction): What details of underdrains, such as pipe length and depth, kind of backfill, etc., cannot be completely obtained from your soil surveys?

TYPE AND LOCATION OF PIPE OR DITCH

11. Check the types of underdrains you use:

| | |
|----------------------|-------------------|
| <u>Perforated</u> | <u>Open-Joint</u> |
| Corrugated metal | |
| Reinforced Concrete | |
| Porous-wall concrete | |
| Tile | |
| Skip | |
| Other | |
12. If perforated, are holes up or down? Do size and spacing of holes conform to the latest (1948) AASHTO recommendations?
13. How are joints installed in open-joint pipe?
14. What diameter(s) of pipe do you use, where only subsurface water is carried?
15. What is usual depth of pipe invert or bottom of ditch below pavement surface?
16. What determines this depth?
17. Is this depth varied, and why?
18. Are you often handicapped by lack of a low outlet point nearby?
19. Do outlets remain open or become plugged?
20. What is depth of frost for a "normal" winter where area is kept bare by snow removal? For a severe winter?
21. What is usual horizontal distance from edge of pavement to underdrain pipe? To bottom of deep open ditch? What is your usual spacing between underdrains at airports?

22. Do you often have underdrains on both sides of the road? Deep open ditches? Do you use herringbone systems of underdrains?

BACKFILL (FILTER) IN TRENCHES

23. What are the gradations for backfill materials? (Give percent passing.)

24. What soils are these various types used for?

25. What tests, if any, are used to determine the ability of the backfill to prevent the soil from clogging it?

26. Do you use coarser material at the perforations and at the open joints than elsewhere? If so, how do you place it?

27. Do you tamp the backfill when placing it?

28. Are there many cases of clogging due to soil being washed into the trench by rain before backfilling is completed?

29. Is impervious soil or other material used to backfill the top portion of underdrain trench to prevent infiltration of surface water?

30. How wide is the trench when backfilled?

PREVIOUS FILL UNDER PAVEMENTS

31. How far beyond edge of pavement is granular subbase placed?

32. Is the subbase carried out continuously to the underdrain trench or ditch or only by bleeders at intervals? What is the spacing of bleeders?

33. What is the usual total thickness of pavement courses plus subbase in earth cuts? In rock cuts?

VERTICAL SAND DRAINAGE WELLS

34. Have you installed any vertical sand drainage wells?

35. Were the results beneficial?

36. What were the benefits, such as saving in cost and in time to complete the project?

37. What were the approximate rates of settlement?

38. Was applied soil mechanics, using test results on undisturbed samples, used in determining the design?

39. Additional remarks:

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DEEP DITCHES OPEN ON BOTH SIDES

Yes
Occasionally
No

| | |
|---|-----------------------|
| X | Alabama |
| X | Arizona |
| X | Arkansas |
| X | California |
| X | Colorado |
| X | Connecticut |
| X | Delaware |
| X | Idaho |
| X | Illinois |
| X | Indiana |
| X | Kansas |
| X | Kentucky |
| X | Maine |
| X | Maryland |
| X | Massachusetts |
| X | Michigan |
| X | Minnesota |
| X | Missouri |
| X | Nevada |
| X | New Hampshire |
| X | New Jersey |
| X | New Mexico |
| X | New York |
| X | North Carolina |
| X | North Dakota |
| X | Ohio |
| X | Oklahoma |
| X | Oregon |
| X | Pennsylvania |
| X | Rhode Island |
| X | South Carolina |
| X | South Dakota |
| X | Texas |
| X | Utah |
| X | Vermont |
| X | Virginia |
| X | Washington |
| X | West Virginia |
| X | Wisconsin |
| X | Wyoming |
| X | E. P. F. * |
| X | B. P. R. Division 5 |
| X | North |
| X | B. P. R. Division 7 |
| X | San Fr California |
| X | Washington U.S |
| X | Boston Eng. |
| X | B. P. R. Division 8 |
| X | Portland, Oregon |
| X | B. P. R. Division 9 |
| X | Denver, Colorado |
| X | C. A. A. |
| X | B. P. R. Division 10 |
| X | Juneau, Alaska |
| X | U. S. A. C. of Engr. |
| X | L. A., California |
| X | U. S. A. C. of Engr. |
| X | San Francisco, Cal. |
| X | U. S. A. C. of Engr. |
| X | Portland, Oregon |
| X | U. S. A. C. of Engr. |
| X | Cincinnati, Ohio |
| X | Bureau of Reclamation |
| X | Denver, Colorado |

HERRINGSTONE U. D. USED

Yes
Occasionally
No

| | |
|---|-----------------------|
| X | Alabama |
| X | Arizona |
| X | Arkansas |
| X | California |
| X | Colorado |
| X | Connecticut |
| X | Delaware |
| X | Idaho |
| X | Illinois |
| X | Indiana |
| X | Kansas |
| X | Kentucky |
| X | Maine |
| X | Maryland |
| X | Massachusetts |
| X | Michigan |
| X | Minnesota |
| X | Missouri |
| X | Nevada |
| X | New Hampshire |
| X | New Jersey |
| X | New Mexico |
| X | New York |
| X | North Carolina |
| X | North Dakota |
| X | Ohio |
| X | Oklahoma |
| X | Oregon |
| X | Pennsylvania |
| X | Rhode Island |
| X | South Carolina |
| X | South Dakota |
| X | Texas |
| X | Utah |
| X | Vermont |
| X | Virginia |
| X | Washington |
| X | West Virginia |
| X | Wisconsin |
| X | Wyoming |
| X | E. P. F. * |
| X | B. P. R. Division 5 |
| X | North |
| X | B. P. R. Division 7 |
| X | San Fr California |
| X | Washington U.S |
| X | Boston Eng. |
| X | B. P. R. Division 8 |
| X | Portland, Oregon |
| X | B. P. R. Division 9 |
| X | Denver, Colorado |
| X | C. A. A. |
| X | B. P. R. Division 10 |
| X | Juneau, Alaska |
| X | U. S. A. C. of Engr. |
| X | L. A., California |
| X | U. S. A. C. of Engr. |
| X | San Francisco, Cal. |
| X | U. S. A. C. of Engr. |
| X | Portland, Oregon |
| X | U. S. A. C. of Engr. |
| X | Cincinnati, Ohio |
| X | Bureau of Reclamation |
| X | Denver, Colorado |

27. JUMP BACKFILL WHEN PLACING

Yes
No

| | |
|---|-----------------------|
| X | Alabama |
| X | Arizona |
| X | Arkansas |
| X | California |
| X | Colorado |
| X | Connecticut |
| X | Delaware |
| X | Idaho |
| X | Illinois |
| X | Indiana |
| X | Kansas |
| X | Kentucky |
| X | Maine |
| X | Maryland |
| X | Massachusetts |
| X | Michigan |
| X | Minnesota |
| X | Missouri |
| X | Nevada |
| X | New Hampshire |
| X | New Jersey |
| X | New Mexico |
| X | New York |
| X | North Carolina |
| X | North Dakota |
| X | Ohio |
| X | Oklahoma |
| X | Oregon |
| X | Pennsylvania |
| X | Rhode Island |
| X | South Carolina |
| X | South Dakota |
| X | Texas |
| X | Utah |
| X | Vermont |
| X | Virginia |
| X | Washington |
| X | West Virginia |
| X | Wisconsin |
| X | Wyoming |
| X | E. P. F. * |
| X | B. P. R. Division 5 |
| X | North |
| X | B. P. R. Division 7 |
| X | San Fr California |
| X | Washington U.S |
| X | Boston Eng. |
| X | B. P. R. Division 8 |
| X | Portland, Oregon |
| X | B. P. R. Division 9 |
| X | Denver, Colorado |
| X | C. A. A. |
| X | B. P. R. Division 10 |
| X | Juneau, Alaska |
| X | U. S. A. C. of Engr. |
| X | L. A., California |
| X | U. S. A. C. of Engr. |
| X | San Francisco, Cal. |
| X | U. S. A. C. of Engr. |
| X | Portland, Oregon |
| X | U. S. A. C. of Engr. |
| X | Cincinnati, Ohio |
| X | Bureau of Reclamation |
| X | Denver, Colorado |

28. CLOGGING BY SOIL WHICH WAS WASHED IN BY RAIN WHEN BACKFILLING

Yes
Occasionally
No

| | |
|---|-----------------------|
| X | Alabama |
| X | Arizona |
| X | Arkansas |
| X | California |
| X | Colorado |
| X | Connecticut |
| X | Delaware |
| X | Idaho |
| X | Illinois |
| X | Indiana |
| X | Kansas |
| X | Kentucky |
| X | Maine |
| X | Maryland |
| X | Massachusetts |
| X | Michigan |
| X | Minnesota |
| X | Missouri |
| X | Nevada |
| X | New Hampshire |
| X | New Jersey |
| X | New Mexico |
| X | New York |
| X | North Carolina |
| X | North Dakota |
| X | Ohio |
| X | Oklahoma |
| X | Oregon |
| X | Pennsylvania |
| X | Rhode Island |
| X | South Carolina |
| X | South Dakota |
| X | Texas |
| X | Utah |
| X | Vermont |
| X | Virginia |
| X | Washington |
| X | West Virginia |
| X | Wisconsin |
| X | Wyoming |
| X | E. P. F. * |
| X | B. P. R. Division 5 |
| X | North |
| X | B. P. R. Division 7 |
| X | San Fr California |
| X | Washington U.S |
| X | Boston Eng. |
| X | B. P. R. Division 8 |
| X | Portland, Oregon |
| X | B. P. R. Division 9 |
| X | Denver, Colorado |
| X | C. A. A. |
| X | B. P. R. Division 10 |
| X | Juneau, Alaska |
| X | U. S. A. C. of Engr. |
| X | L. A., California |
| X | U. S. A. C. of Engr. |
| X | San Francisco, Cal. |
| X | U. S. A. C. of Engr. |
| X | Portland, Oregon |
| X | U. S. A. C. of Engr. |
| X | Cincinnati, Ohio |
| X | Bureau of Reclamation |
| X | Denver, Colorado |

29. IMPERVIOUS MATERIAL AT TOP OF TRENCH

Yes
No
Occasionally

| | |
|---|-----------------------|
| X | Alabama |
| X | Arizona |
| X | Arkansas |
| X | California |
| X | Colorado |
| X | Connecticut |
| X | Delaware |
| X | Idaho |
| X | Illinois |
| X | Indiana |
| X | Kansas |
| X | Kentucky |
| X | Maine |
| X | Maryland |
| X | Massachusetts |
| X | Michigan |
| X | Minnesota |
| X | Missouri |
| X | Nevada |
| X | New Hampshire |
| X | New Jersey |
| X | New Mexico |
| X | New York |
| X | North Carolina |
| X | North Dakota |
| X | Ohio |
| X | Oklahoma |
| X | Oregon |
| X | Pennsylvania |
| X | Rhode Island |
| X | South Carolina |
| X | South Dakota |
| X | Texas |
| X | Utah |
| X | Vermont |
| X | Virginia |
| X | Washington |
| X | West Virginia |
| X | Wisconsin |
| X | Wyoming |
| X | E. P. F. * |
| X | B. P. R. Division 5 |
| X | North |
| X | B. P. R. Division 7 |
| X | San Fr California |
| X | Washington U.S |
| X | Boston Eng. |
| X | B. P. R. Division 8 |
| X | Portland, Oregon |
| X | B. P. R. Division 9 |
| X | Denver, Colorado |
| X | C. A. A. |
| X | B. P. R. Division 10 |
| X | Juneau, Alaska |
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| X | L. A., California |
| X | U. S. A. C. of Engr. |
| X | San Francisco, Cal. |
| X | U. S. A. C. of Engr. |
| X | Portland, Oregon |
| X | U. S. A. C. of Engr. |
| X | Cincinnati, Ohio |
| X | Bureau of Reclamation |
| X | Denver, Colorado |

30. HOW WIDE IS ACTUAL TRENCH

Diem. pipe + 6 in.
Diem. pipe + 8 in.
Diem. pipe + 12 in.
Diem. pipe + 18 in.
12 in.
16 in
18 in
24 in.
30 in.
Variable

| | |
|---|-----------------------|
| X | Alabama |
| X | Arizona |
| X | Arkansas |
| X | California |
| X | Colorado |
| X | Connecticut |
| X | Delaware |
| X | Idaho |
| X | Illinois |
| X | Indiana |
| X | Kansas |
| X | Kentucky |
| X | Maine |
| X | Maryland |
| X | Massachusetts |
| X | Michigan |
| X | Minnesota |
| X | Missouri |
| X | Nevada |
| X | New Hampshire |
| X | New Jersey |
| X | New Mexico |
| X | New York |
| X | North Carolina |
| X | North Dakota |
| X | Ohio |
| X | Oklahoma |
| X | Oregon |
| X | Pennsylvania |
| X | Rhode Island |
| X | South Carolina |
| X | South Dakota |
| X | Texas |
| X | Utah |
| X | Vermont |
| X | Virginia |
| X | Washington |
| X | West Virginia |
| X | Wisconsin |
| X | Wyoming |
| X | E. P. F. * |
| X | B. P. R. Division 5 |
| X | North |
| X | B. P. R. Division 7 |
| X | San Fr California |
| X | Washington U.S |
| X | Boston Eng. |
| X | B. P. R. Division 8 |
| X | Portland, Oregon |
| X | B. P. R. Division 9 |
| X | Denver, Colorado |
| X | C. A. A. |
| X | B. P. R. Division 10 |
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| X | L. A., California |
| X | U. S. A. C. of Engr. |
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| X | U. S. A. C. of Engr. |
| X | Portland, Oregon |
| X | U. S. A. C. of Engr. |
| X | Cincinnati, Ohio |
| X | Bureau of Reclamation |
| X | Denver, Colorado |

