HIGHWAY RESEARCH BOARD

Bulletin No. 45

Subsurface Drainage

1951

HIGHWAY RESEARCH BOARD

PUBLICATION OFFICES

2101 Constitution Avenue Washington 25, D. C.

HIGHWAY RESEARCH BOARD

Bulletin No. 45

SUBSURFACE DRAINAGE

PRESENTED AT THE THIRTIETH ANNUAL MEETING
1951

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL

Washington 25, D. C. December 1951

DEPARTMENT OF SOILS INVESTIGATIONS

Harold Allen, *Chairman*
Principal Highway Engineer,
Bureau of Public Roads

COMMITTEE ON SUBSURFACE DRAINAGE

Philip Keene, *Chairman*
Engineer of Soil Mechanics and Foundations,
Connecticut State Highway Department

Professor Edward S. Barber, Department of Civil Engineering, University of Maryland
John A. C. Callan, A-118, Acting Chief, Standards Coordination Branch, Engineering Division of Office of Airports, Civil Aeronautics Administration
Kenneth Eff, Office, Chief of Engineers, Department of the Army
Seward Horner, Chief Geologist, Kansas State Highway Commission
Carl F. Izzard, Chief, Hydraulics Research Branch, Bureau of Public Roads, U. S. Department of Commerce
Professor C. E. Jacob, Head, Department of Geophysics, School of Mineral Industries, University of Utah
Stanley J. Johnson, Chief, Embankment and Foundation Branch, Waterways Experiment Station, Vicksburg, Mississippi
P. E. Masheter, Assistant Chief Engineer, Bureau of Construction, Ohio Department of Highways, Ohio Departments Building
George W. McAlpin, Jr., Director, Bureau of Soil Mechanics, New York Department of Public Works, State Office Building
Paul Otis, Materials and Research Engineer, New Hampshire State Highway Department
O. J. Porter, 415 Frelinghuysen Avenue, Newark, New Jersey
Carl R. Reid, 625 Dunsmuir Avenue, Los Angeles 36, California
Professor M. G. Spangler, Iowa State College
W. T. Spencer, Soils Engineer, State Highway Commission of Indiana, State House Annex
Dr. Hans F. Winterkorn, Director, Soil Science Laboratory, Princeton University

A REPORT OF THE COMMITTEE ON SUBSURFACE DRAINAGE

PRESENT PRACTICE IN SUBSURFACE DRAINAGE FOR HIGHWAYS AND AIRPORTS

Philip Keene, *Chairman, Connecticut State Highway Department*
and Seward E. Horner, *State Highway Commission of Kansas*

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 ½-or 1½-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 willbe 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 shownin 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

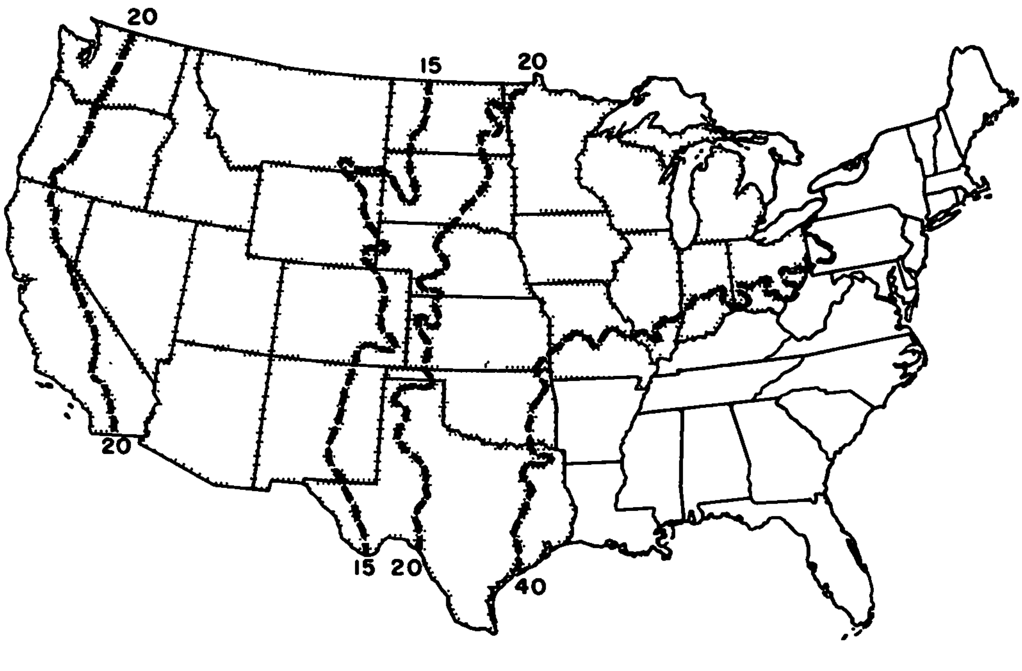

Figure 1. Contours of Precipitation in the United States. The white states have more than 40 in. annual precipitation.

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 intent 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 considerations 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 maintanance 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 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 subbase coarses 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 corrugated-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. Subdrains 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

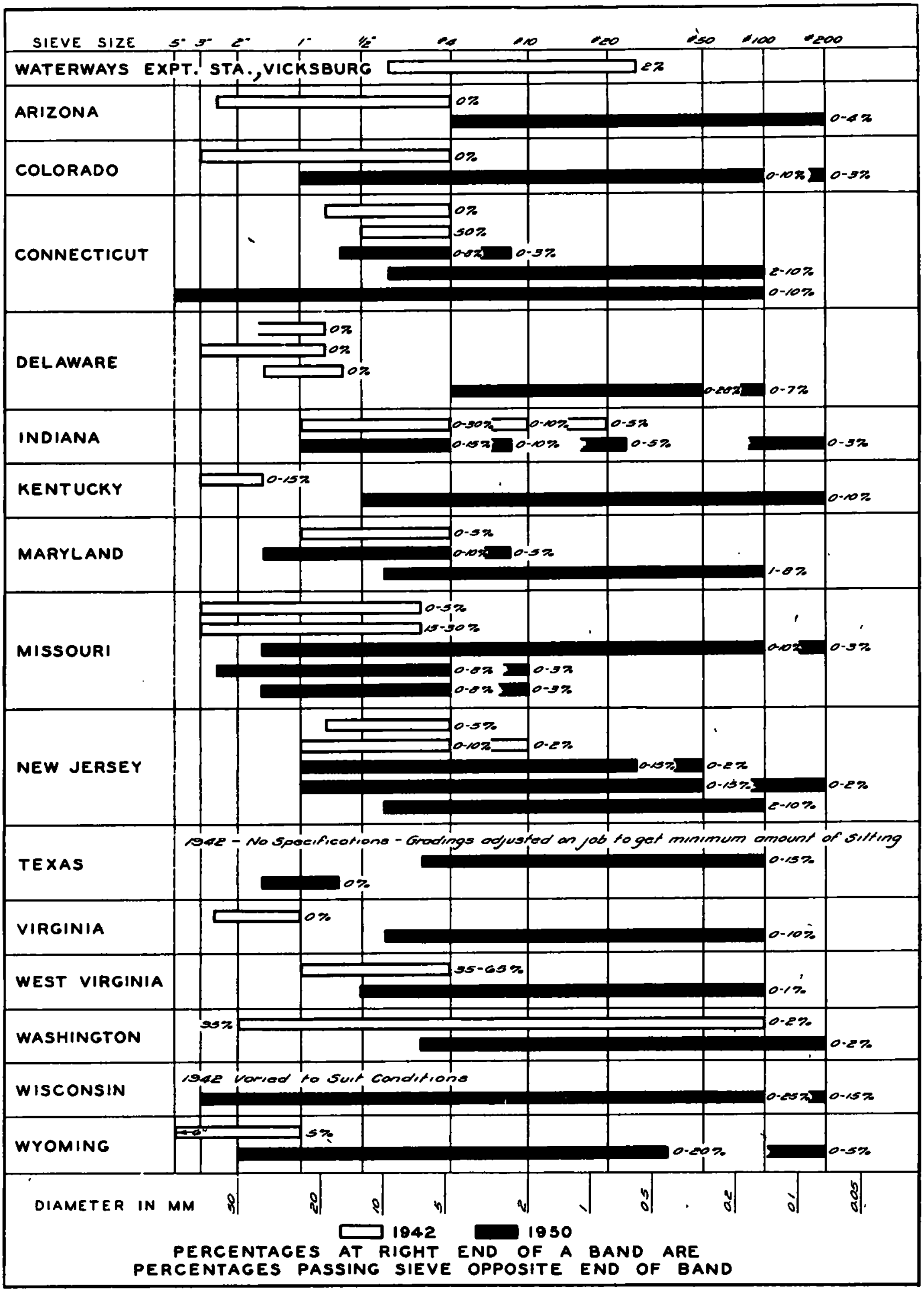

Figure 2. Gradation of Backfill Materials in 1942 and 1950. See Table C for Details of 1950 Gradation.

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 backfilling 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:

	Perforated	Open-Joint
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) AASHO 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:

REFERENCES

1. Muir, Levi, "Present Practice in the Drainage of Highways," *Proceedings*, Highway Research Board, Vol. 22, 1941.
2. U. S. Dept. of Agriculture, 1941 Yearbook of Agriculture. Climate and Man. p. 722, U. S. Govt. Printing Office, Washington, D. C. 1942.
3. Belcher, D. J.; Gregg, L. E.; Jenkins, D. S.; and Woods, K. B.: The origin, distribution, and airphoto identification of United States Soils. U. S. Dept. of Commerce, Civil Aeronautics Administration, Technical Development Report No. 52, Washington, D. C., May, 1946.
4. Kelley, James A.: Microchemical examination of soil solutions. Bureau of Public Roads, Vol. 16, p. 77-89, July, 1935.
5. Horner, S. E., and McNeal, J. D., "Applications of Geology to Highway Engineering," Applied Geology, Quarterly of the Colorado School of Mines, Vol. 45 - Number 1B, p. 155-186, January, 1950.
6. McClelland, T. B., "Large-scale Model Studies of Highway Subdrainage," *Proceedings*, Highway Research Board, Vol. 23, 1943.
7. Investigation of Filter Requirements for Underdrains, U. S. Waterways Experiment Station, Vicksburg, Miss., Technical Memorandum No. 183-1, Nov. 1, 1941.
8. Bleck, A. T.: Pavements and influences affecting or determining their performance. Highway Research Board Bulletin No. 20, pp. 21-69, Sept., 1949.
9. Keene, Philip, "Underdrain Practice of the Connecticut Highway Dept.," *Proceedings*, Highway Research Board. Vol. 24, 1944.
10. Saad, M. A., "Expedient Methods for Stabilizing Swamps," *Proceedings*, Highway Research Board, Vol. 30, 1950.
11. "Subsurface Drainage Investigation, 1945-46", Comprehensive Report and four Appendices, New England Division, Corps of Engrs., U. S. Army, Boston, Mass. Appendix I - Report on Theoretical Analyses of Drainage of Base Courses, L. A. Pipes. Appendix II -Report on Viscous Fluid Model Tests. Appendix III-Report of Field Investigations. Appendix IV - Report on Full Scale Field Drainage Tests.
12. Casagrande, A., and Shannon, W. L., "Base Course Drainage for Airport Pavements", *Proceedings*, Am. Soc. Civil Engrs., Separate No. 75, June 1951.

TABLE B

	Alabama	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Idaho	Illinois	Indiana	Kansas	Kentucky	Maine	Maryland	Massachusetts	Michigan	Minnesota	Missouri	Nevada	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
1. FAILURES IN S.S.D. AND CAUSES																																								
Clogging backfill and pipe	X	X	X	X	X	X	X	X	X	X		X	X	X		X		X	X	X	X		X	X		X		X	X	X		X	X		X	X	X		X	X
Crushing pipe	X								X							X							X																	
Roots in pipe	X		X		X																																			
Outlets clogged	X	X	X	X	X			X	X	X	X					X	X	X														X	X	X			X			
Poor construction						X				X	X					X							X			X	X					X			X					
Impervious soil																				X																X				X
Shallow S S.D	X			X	X					X																	X								X					
None recently															X							X			X															
Landslides																												X									X			
2 PAVEMENT FAILURE AND CAUSES																																								
Breakup, pumping, frost act.		X	X	X		X	X		X	X	X			X		X	X	X	X	X	X		X			X	X	X	X		X			X	X		X			X
Wet Subgrade	X	X	X			X	X	X					X	X		X	X	X	X		X			X					X								X		X	X
Capillary water																																				X	X			
Poor or no S.S.D.				X	X	X			X		X						X							X									X		X				X	
Settlement at S.S.D.														X																	X	X								
Landslides												X																												
3 CRITERIA - will S.S/D. help S.G																																								
Observations and experience		X	X			X			X	X	X		X	X			X		X	X		X						X	X	X			X	X			X			
Soil survey						X			X	X		X	X																					X						
Depth G.W T.	X			X	X	X	X	X			X			X						X	X		X	X													X			
Depth frost						X																																		
Soil type				X		X	X				X			X		X		X					X	X		X	X					X			X		X	X	X	X
Topography	X															X										X												X		X
4. ADD. SUBBASE SUBST FOR S.S.D																																								
Yes	X	X	X	X	X	X		X	X	X		X	X		X	X	X		X	X	X		X	X	X	X		X	X	X	X	X				X	X		X	X
No							X							X								X					X											X		
Added but not substit.	X					X					X							X															X	X	X	X				

	E. P. F.*	B.P.R. Div. 5, No.	B.P.R. Div 7 San. Fr. California	U.S Eng. Washington	U.S Eng. Boston	B.P.R. Div. 8 Portland, Oregon	B.P.R. Div. 9 Denver, Colorado	C.A.A.	B.P.R. Div. 10 Juneau, Alaska	U.S.A. C of E L. A., California	U.S.A. C of E San Francisco, Cal.	U.S.A. C of E Portland, Oregon	U.S.A. C of E Cincinnati, Ohio	Bureau of Reclamation Denver, Colorado
1. FAILURES IN S.S.D. AND CAUSES														
Clogging backfill and pipe	X	X	X	X	X	X	X	X	X				X	X
Crushing pipe				X			X	X	X				X	
Roots in pipe						X	X							
Outlets clogged		X	X			X	X	X					X	
Poor construction		X	X						X		Not Answered			
Impervious soil														
Shallow S S.D			X											
None recently										X		X		
Landslides	X													
2 PAVEMENT FAILURE AND CAUSES														
Breakup, pumping, frost act.	X	X				X		X	X			X	X	
Wet Subgrade			X			X	X	X					X	
Capillary water						X								
Poor or no S.S.D.														
Settlement at S.S.D.					X			X						
Landslides	X													
3 CRITERIA - will S.S/D. help S.G														
Observations and experience		X	X			X	X	X	X					
Soil survey														
Depth G.W T.	X				X	X	X	X				X		
Depth frost														
Soil type					X			X	X			X		
Topography														
4. ADD. SUBBASE SUBST FOR S.S.D														
Yes	X	X	X			X	X		X	X	X			
No					X									
Added but not substit.								X				X		

	Alabama	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Idaho	Illinois	Indiana	Kansas	Kentucky
5 COMBINATION SURF. AND S.S. DRAIN												
Yes												
Occasionally	X					X			X			X
No		X	X	X	X		X	X		X	X	
Bottom half pipe sealed	X											
Bottom half pipe not sealed						X						
Bottom half pipe occasionally sealed									X			
6. WHEN U D. INSTEAD OF DEEP DITCH												
Traffic Hazard	X			X	X					X	X	
Adjacent prop. (R O W)	X						X	X	X	X		
Bad ground water cond.								X	X			
Sidehill or "through cut"		X										X
Rock Cuts		X										
When cheaper										X		X
Difficult maintenance	X				X		X					
Always						X						
Sometimes			X								X	
7 USE INFORMATION IN 'PROCEED'												
Yes	X	X		X	X	X	X		X	X	X	X
No			X									
8 FIELD OR LAB RESEARCH												
None	X	X	X		X		X	X		X		X
Permeability of Backfill												
Filter						X						
Effect of g.w t. depth on heaving						X						
Vert. drains, sand and masonry												
Others				X					X		X	

	Maine	Maryland	Massachusetts	Michigan	Minnesota	Missouri	Nevada	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota
5 COMBINATION SURF. AND S.S. DRAIN													
Yes								X					
Occasionally	X		X	X					X				
No		X			X	X	X			X	X	X	X
Bottom half pipe sealed	X		X	X					X				
Bottom half pipe not sealed								X					
Bottom half pipe occasionally sealed													
6. WHEN U D. INSTEAD OF DEEP DITCH													
Traffic Hazard												X	
Adjacent prop. (R O W)	X			X		X	X	X					
Bad ground water cond.	X												
Sidehill or "through cut"								X		X			
Rock Cuts										X			
When cheaper											X		
Difficult maintenance												X	
Always			X						X				
Sometimes					X								X
7 USE INFORMATION IN 'PROCEED'													
Yes		X	X	X	X	X	X		X	X			
No	X							X			X		
8 FIELD OR LAB RESEARCH													
None	X		X	X	X		X		X		X	X	X
Permeability of Backfill								X					
Filter										X			
Effect of g.w t. depth on heaving													
Vert. drains, sand and masonry		X											
Others						X							

	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming	E. P. F.*
5 COMBINATION SURF. AND S.S. DRAIN																
Yes									X							
Occasionally	X		X	X	X			X				X	X			
No		X				X	X			X				X	X	X
Bottom half pipe sealed				X	X											
Bottom half pipe not sealed								X	X				X			
Bottom half pipe occasionally sealed	X		X													
6. WHEN U D. INSTEAD OF DEEP DITCH																
Traffic Hazard					X			X	X			X	X			
Adjacent prop. (R O W)			X						X	X	X		X		X	
Bad ground water cond.						X		X						X	X	
Sidehill or "through cut"			X	X						X						
Rock Cuts													X			
When cheaper							X					X				
Difficult maintenance							X								X	
Always	X	X														X
Sometimes																
7 USE INFORMATION IN 'PROCEED'																
Yes	X		X						X			X	X		X	
No				X		X	X	X		X	X			X		X
8 FIELD OR LAB RESEARCH																
None				X	X			X		X	X	X	X		X	X
Permeability of Backfill									X							
Filter																
Effect of g.w t. depth on heaving																
Vert. drains, sand and masonry																
Others	X	X	X				X							X		

	B P.R Division 5 North	B.P R Division 7 San Fr. California	Washington U S	Boston Eng	B.P.R. Division 8 Portland, Oregon	B.P R Division 9 Denver, Colorado	C.A.A.	B P.R Division 10 Juneau, Alaska	U.S.A. C of Engr. L. A , California	U S A. C of Engr. San Francisco, Cal	U S A. C of Engr. Portland, Oregon	U.S,A. C of Engr. Cincinnati, Ohio	Bureau of Reclamation Denver, Colorado
5 COMBINATION SURF. AND S.S. DRAIN													
Yes										X			
Occasionally			X			X	X				X		
No	X	X		X	X			X	X			X	X
Bottom half pipe sealed			X				X						
Bottom half pipe not sealed			X			X				X			
Bottom half pipe occasionally sealed													
6. WHEN U D. INSTEAD OF DEEP DITCH													
Traffic Hazard						X		X	X	X		X	
Adjacent prop. (R O W)													
Bad ground water cond.					X								
Sidehill or "through cut"					X								
Rock Cuts													
When cheaper						X		X					
Difficult maintenance					X								X
Always				X			X						
Sometimes	X	X	X										
7 USE INFORMATION IN 'PROCEED'													
Yes	X	X	X	X	X	X	X	X	X	X	X	X	X
No													
8 FIELD OR LAB RESEARCH													
None	X	X	X		X	X	X	X	X	X	X		X
Permeability of Backfill				X									
Filter													
Effect of g.w t. depth on heaving				X									
Vert. drains, sand and masonry													
Others				X								X	

	Alabama	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Idaho	Illinois	Indiana	Kansas	Kentucky	Maine	Maryland	Massachusetts	Michigan	Minnesota	Missouri	Nevada	New Hampshire
9 S.S.D. IMPROVEMENT SINCE 1942																				
Graded and-or finer backfill	X	X		X	X	X	X	X		X		X		X	X	X		X	X	
Deeper or better location						X			X		X								X	
More S.S.D.																				
Use perf A.C.C.M.P.																				X
No Combination drain																				
No french drains			X																	
Full Width sub-base																				
More soil surveys						X	X										X			
None																				
10 DETAILS NOT OBTAINED BY SURVEY																				
Depth				X				X	X						X					
Length				X				X	X											
Diam pipe					X															
Springs or pockets																				
Final details	X	X				X	X				X			X		X		X	X	
Need for S S.D.											X					X				X
None										X		X					X			
11. UNDERDRAIN USED																				
Corr. metal - perf.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Concrete - perf.												X		X						
Concrete open joint	X				X	X			X	X						X			X	
Porous concrete									X			X		X						
Tile - perf.					X				X	X	X	X		X		X		X		
Tile - open joint	X		X	X	X		X		X	X				X		X	X	X	X	
Skip	X													X	X			X		
Others														X				X		

	New Jersey	New Mexico	New York	North Carolina	North Dakota	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
9 S.S.D. IMPROVEMENT SINCE 1942																				
Graded and-or finer backfill	X		X	X		X	X							X		X	X		X	
Deeper or better location				X			X							X	X					
More S.S.D.						X									X					
Use perf A.C.C.M.P.													X							
No Combination drain																				
No french drains																				
Full Width sub-base									X											
More soil surveys												X								
None		X								X										X
10 DETAILS NOT OBTAINED BY SURVEY																				
Depth							X		X			X					X			
Length			X				X					X					X	X		
Diam pipe												X						X		
Springs or pockets								X												
Final details	X			X									X	X		X				X
Need for S S.D.			X																	X
None		X				X									X				X	
11. UNDERDRAIN USED																				
Corr. metal - perf.	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X	X	X
Concrete - perf.								X									X			
Concrete open joint	X		X	X				X	X	X			X	X		X	X			X
Porous concrete	X		X	X				X										X		X
Tile - perf.			X						X											
Tile - open joint	X		X	X	X	X				X	X	X		X	X	X	X	X		X
Skip			X			X			X	X										
Others						X								X	X					

	E.P.F.*	B.P.R. Division 5 North	B.P.R. Division 7 San Fr. California	Washington U.S.	Boston Eng.	B.P.R. Division 8 Portland, Oregon	B.P.R. Division 9 Denver, Colorado	C.A.A.	B.P.R. Division 10 Juneau, Alaska	U.S.A. C. of Engr L. A., California	U.S.A. C. of Engr. San Francisco, Cal.	U.S.A. C. of Engr. Portland, Oregon	U.S.A. C. of Engr. Cincinnati, Ohio	Bureau of Reclamation Denver, Colorado
9 S.S.D. IMPROVEMENT SINCE 1942														
Graded and-or finer backfill	X		X	X	X	X	X	X	X			X		
Deeper or better location														
More S.S.D.														
Use perf A.C.C.M.P.														
No Combination drain					X			X						
No french drains								X						
Full Width sub-base														
More soil surveys								X						
None		X												
10 DETAILS NOT OBTAINED BY SURVEY														
Depth	X						X		X					
Length							X		X					
Diam pipe														
Springs or pockets	X					X		X						
Final details		X	X		X							X		
Need for S S.D.			X											
None				X						X			X	X
11. UNDERDRAIN USED														
Corr. metal - perf.	X	X	X	X	X	X	X		X	X	X	X	X	
Concrete - perf.						X							X	
Concrete open joint	X			X	X					X	X		X	
Porous concrete				X		X						X	X	
Tile - perf.			X											
Tile - open joint	X	X		x	x					X	X	X	X	X
Skip												X	X	
Others											X			

	Alabama	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Idaho	Illinois	Indiana	Kansas	Kentucky	Maine	Maryland	Massachusetts	Michigan	Minnesota	Missouri
12 PIPE PERFORATIONS																		
UP						X									X			X
Down		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Lake 1948 AASHO	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
13. JOINTS OF OPEN-JOINT PIPE																		
Burlap	X			X					X			X						
Tar paper							X					X		X			X	X
B and S or collar					X	X					X					X		
Butt only			X							X								
Clips or lugs																		
14. DIAM. PIPE, S.S. WATER ONLY																		
4 inches							X				X			X				X
6 inches	X		X	X	X	X	X		X	X	X		X	X		X	X	X
8 inches		X	X	X	X			X	X		X	X	X	X	X		X	
10 inches					X						X	X			X		X	
12 inches				X						X	X				X		X	
15 inches																	X	
18 inches																		
24 inches																		
15 DEPTH, PIPE OR DITCH																		
1½ inches		X																
2 inches			X				X					X						X
2½ inches														X				
3 inches	X			X	X		X					X						
4 inches	X			X		X			X	X								
5 inches						X				X					X	X		
6 inches													X					
7 inches													X					
Variable								X			X						X	

	Nevada	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
12 PIPE PERFORATIONS																						
UP							X	X	X	X												
Down	X	X	X	X	X			X		X	X			X	X	X	X		X	X	X	X
Lake 1948 AASHO	X	X	X	X	X		X	X	X	X	X		X	X		X	X				X	X
13. JOINTS OF OPEN-JOINT PIPE																						
Burlap			X		X			X		X			X									
Tar paper	X					X		X			X				X			X		X		X
B and S or collar																	X					
Butt only							X					X		X		X			X			
Clips or lugs																						
14. DIAM. PIPE, S.S. WATER ONLY																						
4 inches	X		X				X						X							X		
6 inches	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X
8 inches	X		X	X	X					X	X	X	X	X		X	X		X		X	X
10 inches																X	X		X		X	
12 inches		X														X			X		X	
15 inches																					X	
18 inches																					X	
24 inches																						
15 DEPTH, PIPE OR DITCH																						
1½ inches																				X	X	
2 inches					X								X						X	X	X	
2½ inches	X										X				X						X	
3 inches					X	X				X	X							X				
4 inches			X		X	X			X		X	X				X						X
5 inches		X	X		X			X	X			X					X					
6 inches							X															
7 inches																						
Variable				X										X								

	E.P.F.*	B.P.R. Division 5 North	B.P.R. Division 7 San Fr. California	U.S. Eng. Washington	U.S. Eng. Boston	B.P.R. Division 8 Portland, Oregon	B.P.R. Division 9 Denver, Colorado	C.A.A.	B.P.R. Division 10 Juneau, Alaska	U.S.A. C. of Engr. L.A., California	U.S.A. C. of Engr San Francisco, Cal.	U.S.A. C. of Engr. Portland, Oregon	U.S.A. C. of Engr. Cincinnati, Ohio	Bureau of Reclamation Denver, Colorado
12 PIPE PERFORATIONS														
UP		X		X		X		X		X				
Down	X	X	X	X	X	X	X	X	X		X	X	X	X
Lake 1948 AASHO	X	X	No		X	X	X	X	X	X	X		X	
13. JOINTS OF OPEN-JOINT PIPE														
Burlap	X			–										
Tar paper		X		–		X					X			X
B and S or collar										X		X	X	
Butt only														
Clips or lugs				X	X			X						
14. DIAM. PIPE, S.S. WATER ONLY														
4 inches		X			X									
6 inches	X	X		X	X	X	X	X		X		X	X	
8 inches	X	X	X	X	X	X	X	X	X		X			
10 inches		X						X	X		X			
12 inches		X							X		X			
15 inches		X									X			
18 inches											X			
24 inches											X			
15 DEPTH, PIPE OR DITCH														
1½ inches														
2 inches														
2½ inches								X						
3 inches		X	X			X	X	X	X	X				
4 inches	X	X	X				X	X	X					
5 inches	X	X	X				X	X	X					
6 inches		X					X	X	X					
7 inches														
Variable											X	X	X	

	Alabama	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Idaho	Illinois	Indiana	Kansas	Kentucky	Maine	Maryland	Massachusetts	Michigan	Minnesota	Missouri
16. WHAT DETERMINES DEPTH																		
Ground water	X			X	X		X	X			X		X		X		X	
Depth of frost					X	X										X		
Soil type				X		X	X		X		X							
Depth of outlet	X					X			X									
Wheel Loads																X		
Local condition										X								X
Specifications																		
17 DEPTH VARIED AND WHY																		
Yes - to ground water				X				X							X		X	X
Yes - if outlet permits																X		
Yes - see question above	X		X		X	X	X		X	X	X	X	X	X				
No		X																
18 OFTEN LACK LOW OUTLET																		
Yes	X		X				X	X	X					X		X		
Occasionally				X	X	X				X	X	X	X		X		X	
No		X																X
19 OUTLETS REMAIN OPEN OR GET PLUGGED																		
Open						X	X					X	X		X			
Usually open	X				X			X	X	X	X						X	
Plugged		X	X	X										X		X		X
20 DEPTH OF FROST-NORMAL WINTER																		
½ foot	X																	X
1 foot		X					X	X		X		X		X				X
1½ feet		X					X	X	X	X	X							X
2 feet		X			X	X		X	X	X	X					X		
2½ feet					X			X		X						X		

	Nevada	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
16. WHAT DETERMINES DEPTH																						
Ground water	X				X					X		X		X	X			X		X		X
Depth of frost		X									X			X			X			X		X
Soil type	X					X								X							X	
Depth of outlet								X					X				X	X				
Wheel Loads																						
Local condition				X												X						
Specifications							X		X										X			
17 DEPTH VARIED AND WHY																						
Yes - to ground water									X	X	X	X			X							
Yes - if outlet permits		X	X				X	X	X	X								X				
Yes - see question above	X			X	X	X							X	X		X	X			X	X	X
No																						
18 OFTEN LACK LOW OUTLET																						
Yes		X						X				X		X	X		X	X				
Occasionally	X		X			X	X			X	X		X						X	X		X
No				X	X				X							X					X	
19 OUTLETS REMAIN OPEN OR GET PLUGGED																						
Open	X	X	X	X	X		X		X			X	X				X	X		X	X	
Usually open						X		X		X				X	X	X			X			X
Plugged											X											
20 DEPTH OF FROST-NORMAL WINTER																						
½ foot	X					X					X		X		X							
1 foot	X		X			X		X	X		X							X	X	X		
1½ feet	X					X		X			X								X			
2 feet	X			X		X		X			X								X			
2½ feet					X			X			X	X				X			X			

	E.P.F.*	B.P.R. Division 5 North	B.P.R. Division 7 San Fr. California	Washington Boston U.S. Eng.	B.P.R. Division 8 Portland, Oregon	B.P.R. Division 9 Denver, Colorado	C.A.A.	B.P.R. Division 10 Juneau, Alaska	U.S.A. C. of Engr L.A., California	U.S.A. C. of Engr. San Francisco, Cal	U.S.A. C. of Engr. Portland, Oregon	U.S.A. C. of Engr. Cincinnati, Ohio	Bureau of Reclamation Denver, Colorado
16. WHAT DETERMINES DEPTH													
Ground water	X	X	X			X	X	X			X		
Depth of frost					X	X	X						
Soil type	X			X			X	X		X			
Depth of outlet		X			X			X					
Wheel Loads							X						
Local condition												X	
Specifications		X							X				
17 DEPTH VARIED AND WHY													
Yes - to ground water			X		X								
Yes - if outlet permits	X		X						X	X			
Yes - see question above		X		X		X	X	X				X	
No													
18 OFTEN LACK LOW OUTLET													
Yes									X				
Occasionally	X	X		X			X					X	X
No			X		X	X		X		X			
19 OUTLETS REMAIN OPEN OR GET PLUGGED													
Open	X		X	X					X			X	
Usually open		X				X	X	X					
Plugged					X								
20 DEPTH OF FROST-NORMAL WINTER													
½ foot		X			X		X				X		
1 foot		X			X		X				X		
1½ feet		X			X	X	X	X			X		
2 feet		X		X	X	X	X	X			X		
2½ feet		X		X	X		X				X		

	Alabama	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Idaho	Illinois	Indiana	Kansas	Kentucky	Maine	Maryland	Massachusetts	Michigan	Minnesota	Missouri
Depth of frost-normal winter (cont.)																		
3 feet					X	X		X		X						X		
4 feet					X	X		X								X	X	
5 feet					X								X		X	X	X	
6 feet					X											X	X	
21 EDGE PAV'T TO PIPE ℄																		
1 foot		X	X						X	X								X
2 feet										X			X					
3 feet										X					X			
4 feet	X					X				X					X	X		
6 feet				X						X					X			
8 feet														X	X			
10 feet							X	X				X						
Variable					X						X						X	
EDGE PAV'T TO OPEN DITCH																		
10 feet		X										X		X				
15 feet	X									X			X					
18 feet																		
20 feet					X				X								X	
25 feet						X					X							
30 feet								X										
40 feet																X		
50 feet																		
100 feet																		
Variable																		X
22. U. D. OFTEN ON BOTH SIDES																		
Yes	X			X	X				X	X	X		X	X		X		
Occasionally		X	X			X	X								X			X
No								X				X					X	

	Nevada	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Texas	Utah	Vermont	Virginia
Depth of frost-normal winter (cont.)																		
3 feet										X	X							
4 feet		X									X			X			X	
5 feet		X					X											
6 feet							X											
21 EDGE PAV'T TO PIPE ℄																		
1 foot																		
2 feet					X			X			X							
3 feet												X						
4 feet		X									X							
6 feet						X				X	X							
8 feet										X	X				X			
10 feet			X	X						X	X							
Variable	X								X					X		X		
EDGE PAV'T TO OPEN DITCH																		
10 feet						X					X	X						
15 feet					X			X										
18 feet																		
20 feet		X													X			
25 feet														X				
30 feet										X								
40 feet																		
50 feet				X														
100 feet																		
Variable	X																	
22. U. D. OFTEN ON BOTH SIDES																		
Yes		X	X		X			X	X	X	X			X	X		X	
Occasionally				X												X		X
No	X					X	X					X	X					

	Washington	West Virginia	Wisconsin	Wyoming	E P F •	B.P.R. Division 5 North	B.P R Division 7 San Fr California	Washington U.S. Boston Eng.	B.P R. Division 8 Portland, Oregon	B.P R Division 9 Denver, Colorado	C.A A.	B.P R Division 10 Juneau, Alaska	U.S.A C. of Engr L.A., California	U S A. C. of Engr. San Francisco, Cal	U S A C. of Engr. Portland, Oregon	U S A C. of Engr. Cincinnati, Ohio	Bureau of Reclamation Denver, Colorado
Depth of frost-normal winter (cont.)																	
3 feet	X					X		X			X				X		
4 feet			X	X		X		X			X						
5 feet			X			X		X			X						
6 feet			X			X		X			X						
21 EDGE PAV'T TO PIPE ℄																	
1 foot		X															
2 feet											X						
3 feet								X							X	X	
4 feet																	
6 feet							X	X	X	X							
8 feet												X	X				
10 feet												X					
Variable	X		X	X		X											
EDGE PAV'T TO OPEN DITCH																	
10 feet									X								
15 feet		X															
18 feet			X														
20 feet																	
25 feet																	
30 feet																	
40 feet																	
50 feet																	
100 feet											X						
Variable				X			X										
22. U. D. OFTEN ON BOTH SIDES																	
Yes			X	X							X					X	
Occasionally	X	X							X	X							
No					X	X	X					X					

	DEEP DITCHES OFTEN ON BOTH SIDES: Yes	Occasionally	No	HERRINGBONE U D. USED: Yes	Occasionally	No	27. TAMP BACKFILL WHEN PLACING: Yes	No	28. CLOGGING BY SOIL WHICH WAS WASHED IN BY RAIN WHEN BACKFILLING: Yes	Occasionally	No	29. IMPERVIOUS MATERIAL AT TOP OF TRENCH: Yes	No	Occasionally	30. HOW WIDE IS ACTUAL TRENCH: Diam. pipe + 6 in.	Diam. pipe + 8 in.	Diam. pipe + 12 in.	Diam pipe + 18 in.	12 in.	16 in	18 in	24 in.	30 in.	Variable
Alabama	X			X			X				X	X						X						
Arizona	X					X		X			X		X									X		
Arkansas		X				X	X				X		X						X					
California			X		X			X			X	X					X							
Colorado			X	X				X			X	X			X									
Connecticut		X				X		X		X		X											X	
Delaware		X			X		X				X	X										X		
Idaho	X					X	X				X		X									X		
Illinois	X				X		X				X			X		X								
Indiana		X			X			X			X	X				X								
Kansas	X					X		X			X			X		X								
Kentucky						X	X			X			X		X									
Maine	X				X		X						X										X	
Maryland	X			X			X				X	X				X								
Massachusetts		X	X		X		X				X		X				X							
Michigan	X					X	X				X		X										X	
Minnesota	X				X			X			X			X										X
Missouri	X				X		X				X			X						X				
Nevada			X		X		X				X	X					X							
New Hampshire	X		X			X	X			X			X				X							
New Jersey	X		X		X			X			X	X				X								
New Mexico			X			X	X				X	X										X		
New York	X		X		X			X		X		X					X							
North Carolina				X			X				X	X					X							
North Dakota			X	X			X				X	X												X
Ohio			X			X		X		X				X										X
Oklahoma			X		X		X				X	X												
Oregon		X		X				X			X		X									X		
Pennsylvania	X			X			X		X				X							X				
Rhode Island			X		X		X				X	X					X							
South Carolina			X		X		X				X		X							X				
South Dakota	X			X			X				X	X									X			
Texas		X		X			X				X	X								X				
Utah			X		X		X				X		X											X
Vermont	X			X				X			X		X										X	
Virginia		X				X	X				X	X							X					
Washington		X			X		X				X		X											
West Virginia		X			X		X			X		X					X							
Wisconsin	X				X			X			X		X									X		
Wyoming	X			X			X				X	X									X			
E.P.F *					X		X			X			X						X					
B.P R. Division 5 North	X				X		X			X		X												X
B.P.R. Division 7 San Fr California			X			X	X				X	X										X		
Washington U.S										X		X												
Boston Eng.							X				X	X										X		
B.P,R. Division 8 Portland, Oregon	X			X				X			X	X											X	
B.P.R. Division 9 Denver, Colorado		X			X		X				X	X										X		
C.A.A.	X				X					X		X					X							
B.P.R. Division 10 Juneau, Alaska			X		X		X				X	X											X	
U S.A. C. of Engr. L.A., California					X		X				X	X						X						
U S.A. C. of Engr. San Francisco, Cal.						X	X					X					X							
U S.A. C. of Engr. Portland, Oregon							X				X	X									X			
U S.A. C. of Engr. Cincinnati, Ohio			X	X			X				X	X					X				X			
Bureau of Reclamation Denver, Colorado											X		X											X

	Alabama	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Idaho	Illinois	Indiana	Kansas	Kentucky	Maine	Maryland	Massachusetts	Michigan	Minnesota	Missouri
31. SUB-BASE BEYOND EDGE PAV'T																		
To u. d. or ditch						X							X		X	X		
Through shoulder		X	X	X	X	X		X		X					X			X
1 ft. minimum									X	X	X	X		X			X	X
2 ft. minimum	X																	
5 ft. minimum																		
32. SUBBASE CARRIED OUT																		
Contin. to u.d or ditch	X	X		X	X	X		X	X		X	X	X	X	X	X	X	
Bleeders to u.d. or ditch										X							X	X
33 PAV'T. + SUBBASE IN EARTH																		
2 in																		
6 in.		X	X														X	
8 in.	X	X	X														X	
9 in.		X															X	
10 in.		X						X									X	
12 in.	X	X	X					X	X			X					X	
15 in		X	X					X	X								X	
18 in.		X	X					X							X		X	
19 in.		X														X		
21 in.		X				X										X		
22 in.																		
24 in						X												
27 in						X							X					
30 in.																		
32 in.						X							X					
Variable				X	X					X	X							X
34, INSTALL. VERT. SANDWELLS																		
Yes				X		X												
No	X	X	X		X		X	X	X	X		X	X	X	X	X	X	
35 WERE RESULTS BENEFICIAL																		
Yes				X		X												
36. SOIL MECHANICS USED IN DESIGN																		
Yes				X		X												

	Nevada	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Texas
31. SUB-BASE BEYOND EDGE PAV'T															
To u. d. or ditch		X													
Through shoulder		X	X				X			X	X	X		X	X
1 ft. minimum	X				X	X							X		
2 ft. minimum								X							
5 ft. minimum															
32. SUBBASE CARRIED OUT															
Contin. to u.d or ditch	X	X	X	X		X		X		X	X	X		X	X
Bleeders to u.d. or ditch					X		X								
33 PAV'T. + SUBBASE IN EARTH															
2 in															
6 in.				X						X					
8 in.				X				X		X					
9 in.	X			X			X	X		X					
10 in.	X			X			X	X		X				X	
12 in.	X			X		X		X		X			X	X	X
15 in	X			X				X		X	X	X	X	X	X
18 in.	X		X		X			X		X			X	X	X
19 in.	X							X		X				X	
21 in.	X	X	X		X			X		X		X	X	X	
22 in.	X							X		X				X	
24 in	X							X		X			X		
27 in								X							
30 in.															
32 in.															
Variable															
34, INSTALL. VERT. SANDWELLS															
Yes			X												
No	X	X			X	X	X	X	X	X	X	X	X	X	X
35 WERE RESULTS BENEFICIAL															
Yes			X												
36. SOIL MECHANICS USED IN DESIGN															
Yes			X												

	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming	E.P.F.*	B.P.R. Division 5 North	B.P.R. Division 7 San Fr. California	Washington U.S	Boston Eng	B.P.R. Division 8 Portland, Oregon	B.P.R. Division 9 Denver, Colorado	C.A.A.	B.P.R. Division 10 Juneau, Alaska	U.S.A. C. of Engr. L.A., California	U.S.A. C. of Engr San Francisco, Cal	U.S.A. C. of Engr. Portland, Oregon	U.S.A. C of Engr. Cincinnati, Ohio	Bureau of Reclamation Denver, Colorado
31. SUB-BASE BEYOND EDGE PAV'T																					
To u. d. or ditch		X				X													X		
Through shoulder	X			X	X		X		X	X			X	X		X					
1 ft. minimum			X					X	X												
2 ft. minimum															X						
5 ft. minimum												X					X	X		X	
32. SUBBASE CARRIED OUT																					
Contin. to u.d or ditch	X	X	X	X	X	X	X		X	X		X		X	X	X	X	X	X		
Bleeders to u.d. or ditch			X					X	X												
33 PAV'T. + SUBBASE IN EARTH																					
2 in														X							
6 in.			X	X			X			X				X		X					
8 in.	X		X	X			X			X			X	X		X					
9 in.	X			X			X			X			X	X		X					
10 in.	X			X			X			X			X	X		X					
12 in.	X		X	X	X		X		X	X			X	X		X					
15 in	X		X	X			X			X			X	X		X					
18 in.	X		X	X			X			X			X	X		X					
19 in.	X			X			X			X						X					
21 in.	X	X	X	X		X	X			X						X					
22 in.	X			X		X	X			X						X					
24 in	X			X		X	X			X						X	X				
27 in	X			X		X	X														
30 in.	X			X			X														
32 in.																					
Variable																		X	X	X	
34, INSTALL. VERT. SANDWELLS																					
Yes				X							X	X	X		X						X
No	X	X	X		X	X	X	X	X	X				X		X	X	X	X	X	
35 WERE RESULTS BENEFICIAL																					
Yes				X							X	X	X		X						X
36. SOIL MECHANICS USED IN DESIGN																					
Yes				X							X	X	X		X					X	X

TABLE C

BACKFILL SPECIFICATIONS (QUESTIONS 23, 24, 25, 26)

STATE	TYPE	PERCENTAGE OF MATERIAL PASSING SIEVE SIZE																							MODIFIED AS NECESSARY	IN WHAT SOILS	COARSE MATERIALS AT PERFORATIONS	TESTS ON BACKFILL MATERIAL		
		5"	3½"	3"	2½"	2"	1½"	1"	¾"	⅝"	½"	⅜"	¼"	#4	#8	#10	#16	#20	#30	#40	#50	#80	#100	#200				PERMEABILITY	GRADATION	PIPING RATIO
ALABAMA	A							100			30/100		10/60			0/25				0/15						ALL TYPES	X			
	B	CONCRETE SAND																												
ARIZONA	A													35/100			46/80				10/30		2/10	0/4		ALL TYPES				
ARKANSAS	A										100		95			80		70		20	15		3	1		ALL TYPES				
CALIFORNIA	A					100		40/100					15/80			6/30			0/6					0/2		ALL TYPES				
	B										100		30/100			65/90	46/70		25/40		10/20		2/8	0/4						
COLORADO	A							100					90/100								10/40		0/10	0/3	X	ALL TYPES				X
CONNECTICUT	A									100	90/100	30/60		0/8	0/3											GLACIAL TILLS (CERTAIN GRAVELY AND [illegible]) OVER PERFORATIONS AND AT OPEN JOINTS	X IF PERF'S UP			
	B											100		85/100			46/80		20/65		10/30		2/10			MEDIUM & FINE SAND, SILTS, & CLAY			X	X
	C	100											30/65							5/30			0/10			ALL TYPES				
DELAWARE	A													85/100							0/25		0/7			SANDY			X	X
IDAHO	A			100									40/100			20/60				6/25				0/8		ALL TYPES	X			
ILLINOIS	A					100							3/100								0/30			0/6		ALL WATER BEARING				
INDIANA	A							100			25/60			0/15	0/10				0/6					0/3	X	ALL TYPES	X			
KANSAS	A	S.E. KANSAS CHATS						100				85/100			40/60				5/25					0/2	X	ALL TYPES WHERE PIPING RATIO HOLDS.				
	B	CRUSHED SANDSTONE						100	60/90					25/45			10/35				0/7		0/2							
	C	CHATS OR CRUSHED FLINT						100				70/100				38/62				10/30			0/2							
	D	SAND AND GRAVEL						100				85/100			40/60				5/25				0/2							
KENTUCKY	A										100				90/100						2/30			0/10		DENSE CLAY				X
MAINE	A						100	NO MATERIAL USED FINER THAN COARSE SAND																		ANY WATER BEARING	X			
MARYLAND	A						100	90/100			25/60			0/10	0/5											ALL TYPES				
	B											100		85/100			46/80		20/60		10/30		1/8							
MASSACHUSETTS	A								100		40/70	0/15		0/5												ALL TYPES	X			
	B										100	85/100		80/100			35/60				10/65		2/10							
	C				100						<70			<80										<5						
MICHIGAN	A				100			90/100												0/100			0/30	0/70	X	ALL TYPES WHERE PIPING RATIO HOLDS	X			
	B					100		70/100			45/100			20/70		10/50				5/30				0/5		MEDIUM AND FINE SAND				
	C							100			75/100			50/70		30/60				20/30				0/5		VERY FINE SAND AND SILT				
MINNESOTA	A					100		75+					25+			0/65				0/15				0/5		ALL TYPES				
	B					100										0/10														
MISSOURI	A						100				65/90					21/60		15/35					0/10	0/3		ALL TYPES	X		X	
	B				100	85/100		35/70			15/30			0/8		0/3														
	C						100	85/100			25/60			0/8		0/3														
NEVADA	A											100		85/100			45/80				5/30		2/10			SILT AND CLAYS		X		
	B							100			0/5															SAND, GRAVEL, & ROCK AQUIFERS				
NEW HAMPSHIRE	A			100									30/70	A FINER, CLEANER GRAVEL OR CONCRETE SAND IS USED IF AVAILABLE.										0/5		ALL TYPES				
NEW JERSEY	A							90/100					20/50						0/15		0/2					AS INDICATED BY U.S.E.D. FILTER DESIGN REQUIREMENTS	X		X	X
	B							100					85/100						0/25		0/10									
	C							100					85/100						45/60		0/15			0/2						
	D	CONCRETE SAND (AASHO SPECIFICATIONS)																												
NEW MEXICO	A								100																X	A-3 SOIL COAL-BEARING SHALE AND SANDSTONE				
	B															>95														
NEW YORK	A					100								30/45										<10		ALL TYPES	X			
NORTH CAROLINA	A							100			0	THIS GRADATION IS TO BE ABANDONED AND REPLACED BY CONCRETE SAND														ALL TYPES				
NORTH DAKOTA	A	NONE GIVEN																									X			
OHIO	A										100	90/100		10/35	0/5											TYPES NOT SPECIFIED		X	X	
	B								100		90/100	40/70		0/15																
	C	SAND																								ALL TYPES				
OKLAHOMA	A												90/100					50/75			8/25		0/5			ALL TYPES				
OREGON	A										100					40/60					5					ALL TYPES	X			
	B	COARSE SAND SUITABLE FOR CONCRETE																												
PENNSYLVANIA	A	100 % PASSING 1½" SIEVE						90/100				25/90	0/10													TYPE A-1	X			
	B											100		10/30	0/10															
	C											100		90/100	70/100			30/70			8/40		0/20	0/10						
RHODE ISLAND	A	100 % PASSING 1½" SIEVE									0			USED AROUND PIPE TO 12" ABOVE PIPE												ALL TYPES			X	
	B			100				0						USED FOR REMAINDER OF BACKFILL ABOVE TYPE A																
SOUTH CAROLINA	A							90/100			25/60		4/12			0/5										TYPES NOT SPECIFIED	NOT GIVEN			
SOUTH DAKOTA	A						100						25/60													ALL TYPES				
TEXAS	A												90/100					50/65					0/15			CONCRETE SAND IN IMPERVIOUS SOILS				
	B						100			0																GRAVEL & STONE IN SANDY SOILS				
UTAH	A							100						45/75		10/50								5	x	ALL TYPES				
VERMONT	A	0/5 PASSING THE #270 SIEVE											0/60										0/12			ALL TYPES				
VIRGINIA	A											100											<10			ALL TYPES				
WASHINGTON	A				>95								30/60												x	ALL TYPES			x	
	B					(							100						25/30					<2						
W. VIRGINIA	A										100		90/100			5/25							0/1			ALL TYPES				
WISCONSIN	A			.95																		<70	<25	<15		ALL TYPES				
WYOMING	A					100										33/75				0/20				0/5		ALL TYPES				
B.P.R. DIV 5 NORTH	A	SAME AS FOR STATE OF WISCONSIN N. DAKOTA S. DAKOTA, MINNESOTA																								SEE MINNESOTA S H D SEE WISCONSIN S H D				
B.P.R. DIV 7 S FRANCISCO	A			100				55/100								13/50								0/5		NOT SPECIFIED				
	B											100		55/100			45/80				10/30		0/10							
B.P.R. DIV 8 PORTLAND	A												100					40/75			10/25		0/15			SILTS AND SILTY CLAY	x			x
	B	CONCRETE SAND																												
B.P.R. DIV 9 DENVER	A			100												35				0/10				0/1		ALL TYPES		x		
B.P.R. DIV 10 JUNEAU	A		100					55/100					25/50			15/45								0/10	x	ALL TYPES				
	B	FINE AGGREGATE FOR P C CONCRETE (PER SPECIFICATIONS F P - 41)																												
B.P.R. DIV OF EASTERN PARKS & FORESTS	A	CONCRETE SAND (SPECIFICATION FP - 41)																								ALL TYPES				
	B	STABILIZED STONE BASE (SPECIFICATION FP-41) WITH THE FOLLOWING EXCEPTIONS:																		<20				<2						
U.S.A CORP ENG WASH D C	A	CONCRETE SAND (MIXTURE OF FINE & COARSE AGGREGATES)																							x	ALL TYPES	x		x	x
U.S.A CORP ENG BOSTON		MODIFIED AS NECESSARY TO MEET THE U.S.E.D FILTER REQUIREMENTS																							x	ALL TYPES	x	x	x	x
U.S.A CORP ENG S FRANCISCO	A								100					0												NO COMMENT				
U.S.A CORP ENG LOS ANGELES	A							55/100	40/85		30/60	0/15		0/5											x	AROUND DRAIN PIPE ALL TYPES	x			
	B													55/100	30/90		15/40		10/20		12/20		13/18							
U.S.A CORP ENG PORTLAND	A	DEPENDENT ON PARENT MATERIAL AND AVAILABILITY OF NATURAL SUITABLE MATERIAL																							x					x
U.S.A CORP ENG CINCINNATI	A	CONCRETE SAND																								FINE SAND & SILTY SOILS		x	x	
	B	BASED ON VICKSBURG TESTS																												
BU. RECLAIM DENVER	A						100																		x			x	x	x
CIVIL AERONAUTICS ADM.	A											100		65/100			45/80				10/30		0/15		x	ALL TYPES	x		x	x
	B						100	90/100				25/60		5/20	0/20															

HIGHWAY RESEARCH BOARD BULLETINS

1	Silicate of Soda as a Soil Stabilizing Agent (1946) 21 pp.	$ .15
2	An Analysis of General State Enabling Legislation Dealing with Automobile Parking Facilities (1947) 110 pp.	(out of print)
3	Report of Committee on Highway Organization and Administration (1947) 23 pp.	.30
4	Report of Committee on Land Acquisition and Control of Highway Access and Adjacent Areas (1947) 42 pp.	.45
5	Report of Committee on Compaction of Subgrades and Embankments (1947) 23 pp.	.30
6	Report of Committee on Uses of Highway Planning Survey Data (1947) 40 pp.	.45
7	An Analysis of State Enabling Legislation of Special and Local Character Dealing with Automobile Parking Facilities (1947) 30 pp.	.30
8	Design of Flexible Pavements Using the Triaxial Compression Test - Kansas Method (1947) 63 pp.	.75
9	Salary and Wage Practices of State Highway Departments (1947) 51 pp.	.60
10	Report of Committee on Land Acquisition and Control of Highway Access and Adjacent Areas (1948) 46 pp.	.60
11	The Polarized Headlight System (1948) 40 pp.	.60
12	Highway Finance (1948) 69 pp.	.75
13	The Appraisal of Terrain Conditions for Highway Engineering Purposes (1948) 99 pp.	1.50
14	Soil Committee Reports and Special Papers (1948) 42 pp.	.60
15	Parking. Committee Report and Three Papers (1948) 31 pp.	.60
16	Expressways, Committee Report and Three Papers (1948) 21 pp.	.45
17	Highway Planning (1948) 45 pp.	.60
18	Land Acquisition and Control of Highway Access and Adjacent Areas, Report of Committee and Four Papers (1949) 44 pp.	.60
19	Parking (1949) 78 pp.	.90
20	Pavement Performance (1949) 74 pp.	.90
21	Maintenance Costs (1949) 20 pp.	.15
22	Engineering Use of Agricultural Soil Maps (1949) 128 pp.	1.80
23	Compaction of Soils, Two Papers (1949) 17 pp.	.15
24	Zoning for Parking Facilities (1950) 161 pp.	3.00
25	Controlled Access Expressways in Urban Areas (1950) 45 pp.	.60
26	The Truck Weight Problem in Highway Transportation (1950) 130 pp.	1.20
27	Road Surface Properties, Report of Committee and Paper on Rubber in Bituminous Pavements (1950) 27 pp.	.45
28	Soil Exploration and Mapping (1950) 124 pp.	1.50
29	Maintenance Costs (1950) 23 pp.	.30
30	Progress in Roadside Protection (1951) 54 pp.	.75
31	Highway Planning (1950) 26 pp.	.45
32	One-Way Streets (1950) 39 pp.	.60
33	Use of Parking Meter Revenues (1951) 30 pp.	.60
34	Reflectors and Night Visibility (1951) 57 pp.	.90
35	Highways with a Narrow Median (1951) 98 pp.	1.50
36	Pavement Marking (1951) 32 pp.	.45
37	Roughness and Skid Resistance (1951) 59 pp.	.90
38	Land Acquisition and Control of Adjacent Areas (1951) 82 pp.	1.20
39	Precasting Bridges and Structures (1951) 20 pp.	.45
40	Load Carrying Capacity of Roads as Affected by Frost Action (1951) 42 pp.	.75
41	Traffic Surveys by Post Cards (1951) 32 pp.	.60
42	Soil Compaction (1951) 23 pp.	.45
43	Studies in Night Visibility (1951) 56 pp.	.90
44	Volcanic Ash and Laterite Soils in Highway Construction (1951) 32 pp.	.60
45	Subsurface Drainage (1951) 23 pp.	.45

NATIONAL RESEARCH COUNCIL

The National Academy of Sciences is a private organization of eminent American Scientists, chartered under a special act of Congress in 1863 to "investigate, examine, experiment, and report on any subject of science or art." The Academy maintains the National Research Council as its operating agency.

The Council, organized with the cooperation of the scientific and technical societies of America, enjoys the voluntary services of more than 2600 scientists making up over 400 standing committees, boards, and panels in all fields of the natural sciences; its membership includes representatives of business and industry. The Council provides advisory and administrative services for research, and attempts to stimulate and coordinate research effort.

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

The National Research Council operates through eight divisions covering fundamental and applied natural sciences, as well as matters of international relations in scientific research. The Division of Engineering and Industrial Research is concerned with the stimulation and correlation of research in a wide variety of fields in engineering and the applied sciences.

HIGHWAY RESEARCH BOARD

The Highway Research Board is organized under the auspices of the Division of Engineering and Industrial Research of the National Research Council. Its purpose is to provide a national clearing house for highway research activities and information. The membership consists of 42 technical, educational, industrial, and governmental organizations of national scope. Associates of the Board are firms, corporations, and individuals who are interested in highway research and who desire to further its work.

The purposes of the Board are: "To encourage research and to provide a national clearing house and correlation service for research activities and information on highway administration and technology, by means of: (1) a forum for presentation and discussion of research papers and reports; (2) committees to suggest and plan research work and to correlate and evaluate results; (3) dissemination of useful information and (4) liaison and cooperative services."