Wiest). Princeton University Press, Princeton, N.J., 1962.
15. S.J. Liu, J.K. Jeyapalan, and R.L. Lytton. Characteristics of Base and Subgrade Drainage of Pavements. In Transportation Research Record 945, TRB, National Research Council, Washington, D.C., 1983, pp. 1-10.
16. S.J. Liu and R.L. Lytton. A Simulation Model for Rainfall Infiltration, Drainage Analysis, and Load-Carrying Capacity of Pavements. Texas Transportation Institute, Texas A&M University, College Station, Aug. 1983.
17. S.H. Carpenter, M.I. Darter, and B.J. Dempsey. A Pavement Moisture Accelerated Distress (MAD) Identification System--Volume 2. Report FHWA-RD-81-080. FHWA, U.S. Department of Transportation, 1981.
18. J.H. Haynes and E.J. Yoder. Effects of Repeated Loadings on Gravel and Crushed Stone Base Course Materials Used in the AASHTO Road Test. In Highway Research Record 39, HRB, National Research Council, Washington, D.C., 1963, pp. 82-96.
19. M.R. Thompson and Q.L. Robnett. Resilient Properties of Subgrade Soils. ASCE, Journal of Transportation Engineering, 1979, pp. 71-89.
20. R.L. Lytton and C.H. Michalak. Flexible Pavement Deflection Equation Using Elastic Moduli and Field Measurements. Research Report 207-7F. Texas Transportation Institute, Texas A&M University, College Station, Aug. 1979.

Publication of this paper sponsored by Committee on Subsurface Drainage.

Implementation of Internal Road Drainage Design and Application

GEORGE S. KOZLOV

ABSTRACT

As a result of more than 5 years of research, which culminated in the construction of two experimental, internally drainable road sections, it is now possible to present engineers with procedures for the design, construction, and maintenance of adequately drainable roads. These procedures are offered as a guide until their further application would provide additional data for improvements. It is suggested that adequate surface drainage, combined with appropriate internal drainage, is the most advantageous solution to the problem of water buildup beneath a roadway.

Research by the New Jersey Department of Transportation (NJDOT) has established that improved pavement durability can be realized if water is not allowed to accumulate within the structural section of a pavement. Therefore use of a drainage layer immediately below the lower bound layer of a pavement has been found to be the most effective means of achieving the necessary degree of internal drainage. This system is designed to handle surface infiltration water only.

However, groundwater drainage systems will be used only when groundwater is deemed to be a problem. It can be in the form of longitudinal or transverse drains to intercept flow, or drainage blankets or well systems to lower the water table and relieve pore water pressure. In this way the two internal water drainage sources previously mentioned call for two totally and distinctly different drainage approaches and solutions.

SUMMARY OF SUPPORTING RESEARCH

As part of the research study, a field investigation of the existing underdrainage conditions of New Jersey highways was performed. The field surveys indicated a definite need for better internal drainage solutions. Subsurface drainage failure under portland cement concrete pavements was found to be manifested by pumping, cracking, and eventual disintegration of the surfacings. Water-related deterioration of bituminous concrete pavements appeared to occur no less often; however, the relationship was often not visually apparent. It appeared that the type of surfacing had little effect on the moisture conditions immediately below a pavement.

The survey of New Jersey highways included a performance evaluation of several previous subsurface drainage solutions. The conclusion, in essence, was that longitudinal pipe drains, after-the-fact solutions, or even initial installations apparently are not adequate to handle the subsurface drainage of infiltrated roofwater. Thus the objective of this project became the development of the pavement design process.

Specifically, it was intended that the research formulate the design methods and the construction and maintenance procedures for a drainage system that would control water within New Jersey pavements. To this end, an exhaustive study of the state of the art, extensive laboratory investigations, and some experimental field installations were conducted. To minimize the amount of surface water entering a pavement, it is obvious that every effort should be made to have a fully effective surface drainage system. Therefore, as part of the study, a practical surface drainage guide was prepared for use with the small drainage areas typically encountered in highway design (1). For subsurface drainage of the water that does get into a pavement, the literature review and results of the field surveys indicated that solutions proposed by Cedergren et al. (2) offered some promise for success.

The most important element of the Cedergren approach is the drainage layer. Such a system can be achieved if a drainage layer is provided that satisfies three basic requirements: It must be open enough to drain water in a reasonable length of time, yet with low enough flow rates to prevent internal erosion; it must be dense enough to support traffic loads; and it must possess filtration characteristics compatible with base and subbase materials. The development of materials that satisfied these requirements proved to be extremely difficult and became the object of a significant portion of the literature assessments and most of the laboratory work.

To design an effective drainage layer it was first necessary to identify flow theories for open-graded materials. Darcy's flow equation, even though only applicable to laminar conditions in fine grain soils, appeared somewhat useful in developing upper bounds on horizontal flow rates in an open-graded layer. In the end, horizontal flume tests had to be undertaken to confirm that the final drainage layer materials would perform effectively.

The actual design of the drainage layer began with an attempt to satisfy the requirement of removing infiltrated water in a reasonable time period. To preclude water freezing within a drainage layer and to avoid extensive periods of saturated pavement materials, achieving 50 percent drainage within 24 hr was concluded to be more appropriate for highways. For a selected drainage layer thickness of 4 in. and considering New Jersey's climatic conditions, probable rainfall, and possible infiltration rates, the 24-hr criterion led researchers to establish a needed minimum permeability of 1,000 ft per day within the drainage layer. However, from subsequent laboratory evaluations of available drainage layer materials, it was found more appropriate to establish a desired permeability range of 1,000 to 3,000 ft per day. With this restricted permeability range it was possible to isolate materials that also had adequate stability and filtration properties.

Several field construction trials were used to help direct and verify the laboratory efforts at developing adequate drainage layer materials. From these combined activities it was possible to formulate materials and construction specifications for nonstabilized open-graded (NSOG) and bituminous-stabilized open-graded (BSOG) layers.

PROCEDURES FOR DESIGN, CONSTRUCTION, AND MAINTENANCE

Design of Drainage for Surface Water Infiltration

The validity of the design procedures presented in this paper depend on the accuracy and completeness of the design and application requirements. The solutions developed by this research are as realistic as possible, while still retaining engineering integrity.

The requirements for the design and application of the subsurface drainage can be placed in the following categories:

1. The geometry of the flow domain,
2. The properties of the materials,
3. The application of the drainage facilities and the means for applying them, and
4. The climatological data.

The geometry of the flow involves the geometric design of the highway, related subsurface drainage geometry, and prevailing conditions. The fundamental properties of the drainage material, such as permeability, density, geological characteristics, and particle shape, define the performance of the material. To perform properly, drainage material must transmit the flow of water, properly support loads, and, most important, retain these characteristics for a reasonable life span of a road. Proper use of such characteristics in the design and application of the drainage facilities also requires suitable lifetime maintenance. The climatological data provide insight into the fundamental source of all subsurface water and the potentially adverse effects of frost action.

Highway and Subsurface Geometry

Almost all of the geometric design of subsurface features of a highway can exert some influence on the analysis and design of subsurface drainage. Therefore, before attempting to undertake such work, the designer should be armed with as much information as possible on these features. Included should be sufficiently detailed profiles and cross sections to permit assembly of the following data for each section of roadway under consideration: longitudinal grades; transverse grades (including superelevations); widths of pavement and shoulder surface, base, and subbase; required thickness of pavement elements based on normal structural design practice for the particular area under consideration; depths of cuts and fills; recommended cut and fill slopes; and details of ditches and other surface drainage facilities. In addition, it is considered desirable to have a topographic map of the highway corridor on which the final highway alignment has been superimposed.

The flow of water in the structural section (drainage layer) of the pavement is largely controlled by the longitudinal grade of the roadway and its cross slope. When the profile of a road is relatively flat, water entering the drainage layer will flow laterally by virtue of the cross slope of the layer and empty into the longitudinal drainage trenches. However, when there is a profile grade, the water will also flow somewhat in the direction of the grade.

For a particular roadway site, a good estimate of the flow path length for a single lane of pavement can be obtained by using the equations that follow. Also, an equation is provided for distance of flow parallel to the grade that is helpful in establishing the actual station locations of any needed cross drains.

$$S_1 = \sqrt{S_{cross}^2 + S_{long}^2} \qquad (1)$$

$$L = W\sqrt{1 + (S_{long}/S_{cross})^2} \qquad (2)$$

$$L_G = W(S_{long}/S_{cross}) \qquad (3)$$

where

S_{cross} = highway lane cross slope (ft/ft),
S_{long} = highway lane longitudinal slope (ft/ft),
S_1 = slope of the underdrain layer (path) (ft/ft),
W = width of drainage layer (lane width) (ft),
L = length of flow path (ft), and
L_G = distance water has traveled in the direction parallel to the grade (ft).

Transverse drains must be used at each underdrain outlet to convey water from the longitudinal drains to the outlet facility. Except for vertical sag and superelevated curve conditions, transverse drains should be placed at about a 45-degree angle to the longitudinal pipe line. In hilly terrain the cross drains should be required wherever needed to prevent the flow paths from exceeding approximately 150 ft.

The location of outlets will often be dictated by topograhpic and geometric features and overall drainage pattern; nevertheless, as a general rule, the spacing of outlets should not exceed 500 ft.

Normally the outlet pipes should be daylighted. If this is not possible, then they should be drained into the nearest inlet structure. When the latter is the case, it is imperative that the flow line of the subsurface drainage system pipe be at least 6 in. higher than the maximum predicted water surface in the inlet to avoid storm water backing up into the subsurface drainage system.

Design of Subsurface Drainage Layer

The infiltration of water into the pavement has been practically resolved so as not to require the knowledge of the water movements, as will be shown later. The drainage layer developed by NJDOT has the capacity to drain off the water in a reasonably short time, that is, before it can cause jeopardy to the structural capacity of the pavements. As already indicated and shown on standard details (Figures 1-4), the drainage layer should be located immediately below the bound layer of a pavement under a minimum of 6 in. of confinement. Figures 1 and 3 give the cross-sectional view of a drainage layer, its edge drains, and a typical cross drain for a generalized highway pavement. Figure 1 provides an alternate whereby the longitudinal edge drains are positioned at the edge of the pavement, whereas Figure 2 shows the same drains located at the edge of the shoulder. The alternave shown in Figure 2 is preferred, but if construction costs are of major concern or if the design considerations require, the approach shown in Figure 1 can be used. Figures 1 and 2 have the cross slopes and grade breaks of the drainage layer mirroring the pavement surface. Details in Figures 3 and 4 are basically duplicates of Figures 1 and 2, except that a constant cross slope is required of the drainage layer. From a long-term performance standpoint, construction in accordance with the details shown in Figures 3 and 4 are best. However, for ease of construction, but not necessarily for minimized installation costs, the configuration shown in Figures 1 and 2 will frequently be found more appropriate. Of course, variations of Figures 1-4 are entirely feasible as long as they are appropriately developed.

Principles of Subsurface Drainage

The roofwater drainage layer developed in this research is open enough to drain water in a reasonable amount of time, yet its flow is close to laminar. Also, this layer is dense enough to support traffic loads, while possessing filtration characteristics compatible with the base or subbase materials. Be-

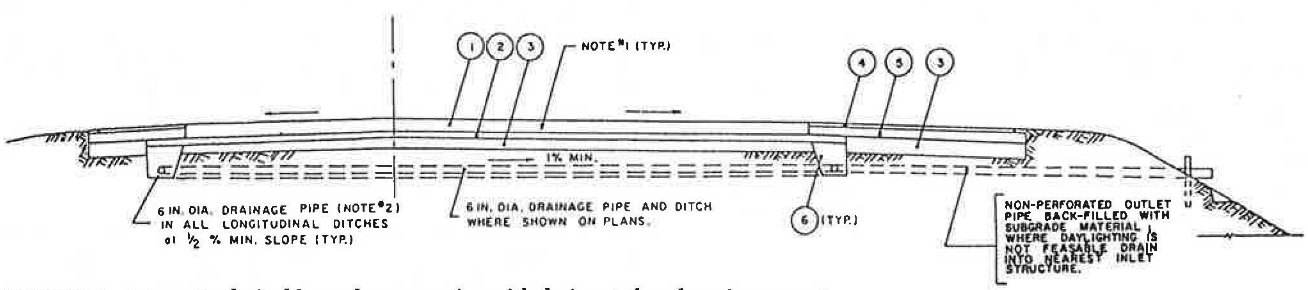
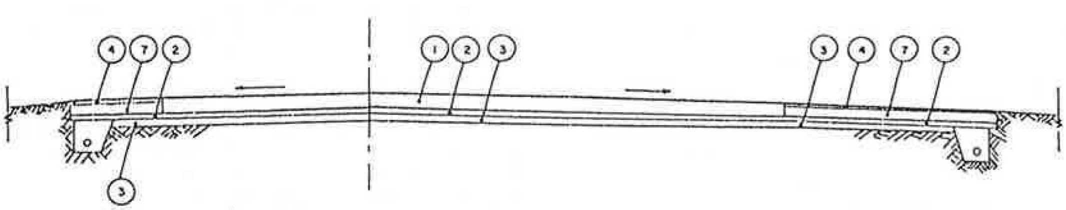


FIGURE 1 Internally drainable road cross section with drains at the edge of pavement.



(1) B.C. OR P.C.C. PAVEMENT, MIN. 6 IN. THICK
(2) 4 IN. B.S.O.G. OR N.S.O.G. DRAINAGE LAYER
(3) BASE OR SUBBASE LAYER.
(4) B.C. SHOULDER
(5) SOIL AGGREGATE OR DENSE GRADED AGGREGATE BASE LAYER.
(6) 8 OR 57 COURSE AGGREGATE
(7) L.F.A. PLANT MIXED STABILIZED BASE COURSE OR NONSTABILIZED BASE COURSE OVER FILTER FABRIC.

NOTES 1. USE PRIME COAT ON THE TOP OF THE NSOG LAYER.

2. DRAINAGE PIPE SHALL BE PERFORATED OR SLOTTED CORRUGATED METAL, PVC OR PE PLASTIC OR POROUS WALL CONCRETE PIPES.

FIGURE 2 Internally drainable road cross section with drains at the edge of shoulder.

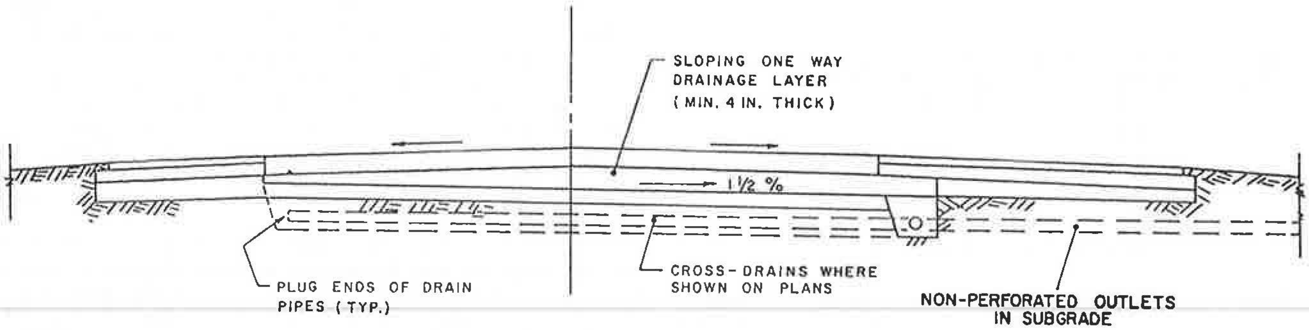


FIGURE 3 Road cross section drainable to the edge of pavement collector.

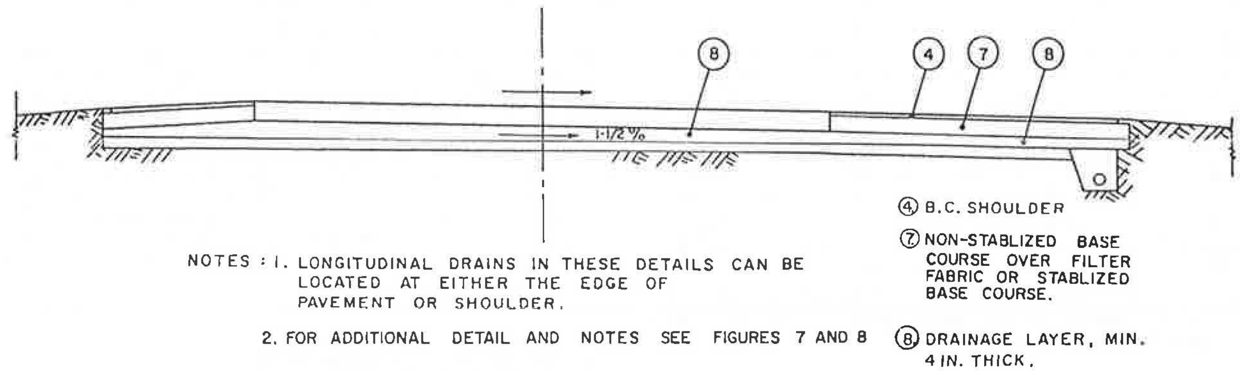


FIGURE 4 Road cross section drainable to the edge of shoulder collector.

cause there is practically no way to prevent the penetration of roofwater into pavements nor is it practical to drain this water any other way but horizontally, a drainage layer invariably should be used in all roads if the problems associated with water in pavement are to be solved.

As already indicated, the principles of subsurface drainage that have been adopted here suggest that only the drainage capacity of the drainage layer determines the quantity of water to be drained. This quantity of water will generally be less than the capacity of the drainage pipes in the longitudinal edge drains. Therefore, the capacity of a drainage layer can then be calculated by Darcy's equation:

$$Q = KAi \tag{4}$$

where

- Q = discharge quantity (ft^3/day) per foot of longitudinal drainage pipe length,
- K = permeability constant (ft/day),
- i = H_o/L = hydraulic gradient (ft/ft),
- A = H x 1.0 cross-sectional area of drainage layer (ft^2) per unit width of the layer,
- L = length of flow path through the soil (ft),
- H = thickness of open-graded layer (ft),
- H_o = H + L tanα (ft), and
- tanα = slope of the base layer.

The next parameter of importance is the time of drainage. To keep structural water damage at an absolute minimum, the total removal of water within a reasonable time span is desirable. If the amount of water to be drained is given by n_eAL, the Darcy fundamental equation, when solved for time t, yields

$$t_{total} = n_e L^2 / [K(H + L \tan\alpha)] \tag{5}$$

where t_{total} is the time of total drainage of the free moisture a layer can drain (days), and effective porosity (n_e) = (volume of voids that can be drained)/(total volume).

Most investigators agree that the subsurface drainage must be capable of removing within a short enough time span 50 percent of unbound moisture it can drain. This requirement prevents the freezing effect of the water from damaging the pavement structure. Using Casagrande's (3) flow equations for time, the 50 percent drainage point is expressed as

$$t_{50} = n_e L^2 / [2K(H + L \tan\alpha)] \tag{6}$$

where t_{50} is the time of drainage of 50 percent of the unbound moisture a layer can drain (days). Effective porosity has been found to equal approximately 80 percent of the absolute porosity (n) for granular type materials.

With flow conditions of open-graded materials bordering on the turbulent, the flow rates will be lower than those predicted by Darcy's fundamental law. The magnitude of the flow rate in this instance would be a matter of conjecture, because little work has been done in studying turbulent flow in soils. In any case, because of possible turbulent conditions, there needs to be an extremely stable grain structure in the drainage layer.

Application of Open-Graded Drainage Layer

In any internal road drainage design, either the NSOG or the BSOG layers can be used with the appropriate collector system. Initially, the NSOG material was developed primarily for use in rigid pavement designs, whereas the BSOG drainage layer was meant for use in flexible pavements. It was originally theorized that for the unbound NSOG material, rigid pavement would provide better and more uniform load distribution, whereas the BSOG layer, with its stability provided by asphalt, would be more compatible with flexible pavements. Thus far the NSOG material has been found to be somewhat better from a structural performance standpoint. However, BSOG is easier to construct. Currently, it does not appear that there will be a great differential in cost between the two material types. For structural design purposes, both NSOG and BSOG can be assumed to have a structural index equivalent to NJDOT dense-graded aggregate base (SN = 0.14).

It is imperative that both materials are applied with some type of barrier, be it some form of soil stabilization, filter cloth, or filter-type soils under, above, or adjacent to the open-graded layer and drainage trenches. Although the use of soil stabilization or filter fabric might increase the cost of drainable pavement if materials compatible with filter requirements (such as the subbases typically specified for New Jersey roadways) are placed under the open-graded layer, no additional cost should be incurred. If structural strength advantages were ascertained in flexible pavement design, the use of lime-fly ash soil stabilization could provide considerable cost savings.

NSOG Material Properties and Laboratory Procedures

The NSOG material must comply with the gradation band shown in Figure 5 and the composition of the mixture given in the following table. The material for this layer shall consist of crushed aggregate conforming to the following gradation requirements:

Sieve Size	Allowable Percent Passing
1.5 in.	100
1 in.	95-100
0.5 in.	60-80
No. 4	40-55
No. 8	5-25
No. 16	0-8
No. 50	0-5

The material can be made of a 50/50 blend of No. 57 and No. 9 stone or might be produced as a new standard size mix of coarse aggregates. Even though only three specific stone sources (limestone, trap rock, and gneiss) could be tested, these materials are representative of the predominant stone types available for NJDOT construction work. However, because these were not all-inclusive tests and were laboratory rather than field investigations, caution is suggested when using crushed stone from other sources. There are many stone sources and even a few other stone types that are currently acceptable for New Jersey projects. The producer of NSOG material, therefore, is required to submit for approval a particular target gradation that is within the band and can be produced with his aggregate sources. The permeability testing and density and gradational stability evaluation with the Burmister vibratory table are essential, and submission of samples for such purpose is required. The final approval of the material is based on the target gradation having permeability of 1,000 to 3,000 ft per day and a stable voids system. Gradational stability does not imply the structural strength of a material, but rather it is based on visual aspects (i.e., minimum of voids, degree of migration, and segregation; hence a stable voids system). When a sample is compacted into a Plexiglas mold it is visually evaluated for low void content and absence of segregation, and then density is measured directly in the mold. If No. 57 and No. 9 stone are mixed, they must individually meet grading specifications and in any case be of the same source (i.e., stone type) because mixing of stone types might impair the performance of the drainage layer.

To assure that adequate conditions are achieved in the field, in-place gradations are required to be close to the target gradation. The density of the material, while being close to that achieved in the Burmister mold, must be the maximum attained in the control strip test.

To ascertain that the requirements previously mentioned and specified in the NSOG construction and

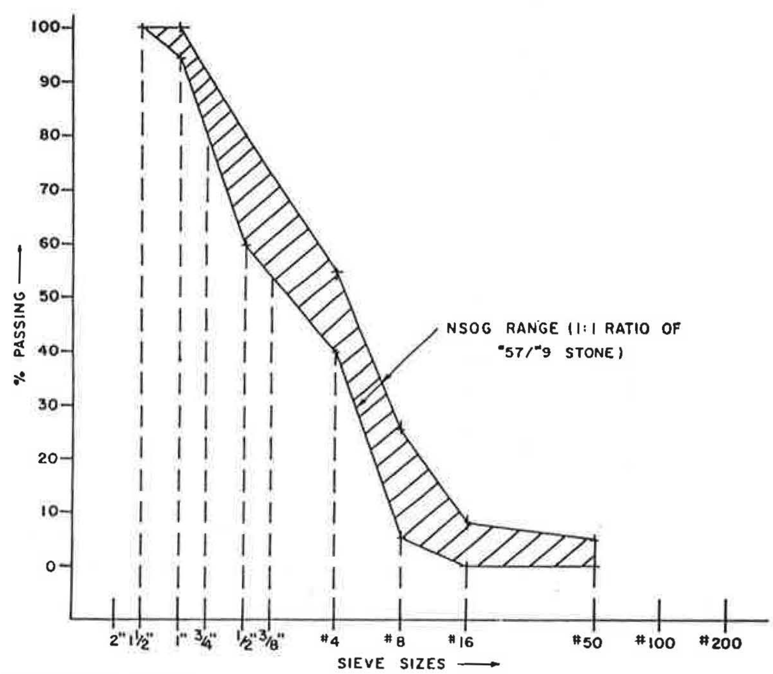


FIGURE 5 NSOG gradation range.

material specification are met, new falling head permeability and modified compaction tests are provided (4). The specified permeameter served well throughout the research study. The equipment can be used with confidence on materials that have a K factor ranging from 100 to 20,000 ft per day. This permeameter gives reasonable repeatability, and the permeability constant K values are probably slightly conservative, and hence applicable to the subject engineering problems. When used as a permanent piece of equipment, it should be improved and standardized for manufacturing purposes.

To duplicate field compaction conditions, laboratory compaction procedures for NSOG material were developed and provided by the specification (4). ASTM specification D2049 provides Burmister vibratory table test procedures for compaction of cohesionless soils. The Burmister equipment was modified for testing the open-graded materials, as it is described in specifications (4). A Plexiglas mold was used to allow viewing of the samples for evaluation of their gradational stability and density measurements. The relatively large Plexiglas cylinder mold, capable of holding 15 lb of uncompacted NSOG materials, proved to be essential for obtaining representative density results. For permeability tests, a 4-in. metal mold is used with a 1600-g specimen for compatibility with the permeameter. This equipment should also be standardized for manufacturing purposes.

It should be noted here that wet stone densities were lower than dry stone, on the average by approximately 8.5 percent. Also, there appears to be no migrations of the fine material to the bottom of the sample, although considerable migration of fines could be observed in dry samples. The presence of water appears to decrease the density and lessen the migration of fines. Therefore, although wet stone will be used in the field to minimize segregation, in laboratory compaction only dry stone must be tested.

BSOG Material Properties and Laboratory Test Procedures

The BSOG material must comply with the gradation band shown in Figure 6 and the composition of the mixture given in the following table. The BSOG material shall consist of bitumen, antistripping agent, and aggregate that conform to the following gradation requirements:

Sieve Size	Allowable Percent Passing
1 in.	100
0.75 in.	95-100
0.5 in.	85-100
0.375 in.	60-90
No. 4	15-25
No. 8	2-10
No. 16	2-5
No. 200	-

[Note that for the No. 200 sieve, 2 percent (by weight of total mix) mineral filler should be added. Also note that the bitumen content shall be 3 ± 0.5 percent by weight of dry aggregate and mineral filler.] This gradation, made of No. 8 stone size, is modified by the addition of some large size aggregate to lower material cost. Because the material passing the No. 4 screen and retained on the No. 8 screen controls the permeability, the BSOG gradation specifications of the No. 4 screen are also tightened.

The asphalt content for the BSOG material should always be set at 2 to 3.5 percent. The lower limit of this range was determined on the basis of a thorough coating of the stone particles. The upper limit, on the other hand, was established when the excess of the asphalt content begins to drain. Admixing of an antistripping agent to the asphalt is required for field applications. Also, a small amount of mineral filler (2 percent) is used to

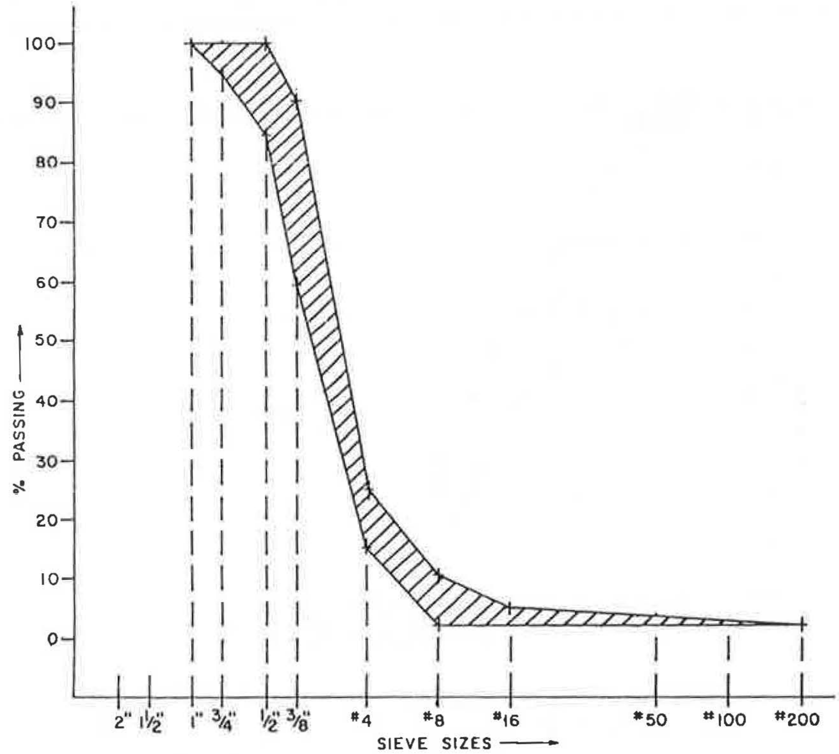


FIGURE 6 BSOG gradation range.

stiffen the asphalt cement, to reduce asphalt drain off, and to improve mixture cohesion.

As in the case of the NSOG material, the contractor is required to submit for approval a particular target gradation that is within the band. The design approval is based on the NJDOT laboratory test of mixture permeability. The compaction of the BSOG material is achieved with a Universal testing machine at pressures of 1,000 psi for trap rock and gneiss and 600 psi for limestone materials. This provides permeabilities within the required range of 1,000 to 3,000 ft per day. Field permeabilities should be somewhat higher than the laboratory values because the compaction process with the Universal testing machine tends to create a more closed surface than that achieved in the field.

It should be recognized that the laboratory compaction data can serve as a guide for field densities. Because the laboratory compaction pressures evolved from an attempt to match achievable field densification, the laboratory densities could be used as a rough indication of the probable field density. However, it could not be used as a target because maximum density achieved on a control strip should be the only acceptable target. Nevertheless, a general equivalency between laboratory and control strip field data offers some assurance that permeability levels in the field are somewhat comparable with laboratory values.

To assure compliance with the requirements and the specifications previously given, permeability tests and modified Universal testing machine compaction procedures are provided. ASTM specification D1075, as used in the Immersion Compression Test, was modified to suit the specific needs of BSOG material compaction. The major modification for testing drainage layer materials consisted of decreasing the compaction pressure specified in the test. This was done to minimize the effect of the apparent crushing of particles, which had caused considerable changes in gradation--a phenomenon that did not occur in the field. Again note that because the researcher could look only at a limited amount of New Jersey sources, caution must be exercised when new sources or stone types are being introduced.

Design of Water-Collection Systems

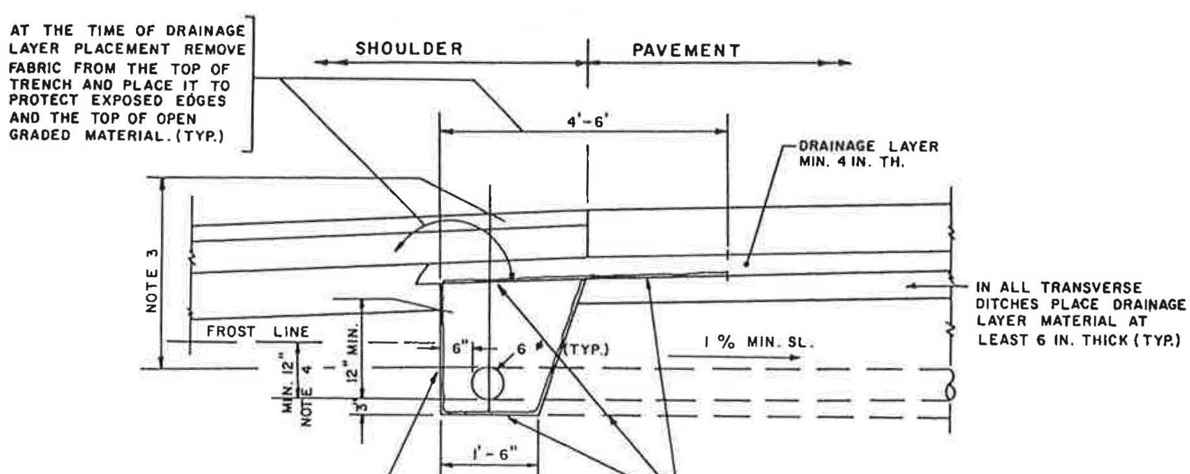
General

Some of the features of water-collection systems were already discussed in the subsurface geometry analysis. Basically, physical features such as the use of longitudinal and transverse drains, the angle of outlets, daylighting or draining the outlets into the inlet structures, and the like were discussed. The geometric analysis of the location, spacing, and arrangement of collectors was also made.

At this point two factors concerning internal drainage collection should be mentioned. One is vertical drainage, and the other is daylighting of the drainage layer instead of draining it into the edge drains. The vertical drainage of the infiltration water is impractical because of the impervious nature of the subbase and the complexity and cost of the solution for determination of the drainage characteristics of the subgrade. On the other hand, the daylighting principle, at a glance, appears tempting mainly because it is so much cheaper. However, it is a generally well-known fact that it is not uncommon for this type of outlet to become clogged and cease to function. This would mean a water buildup under the pavement resulting in a rapid deterioration of the pavement structure. Thus a drain that contains a pipe is the only positive mode of water collection that appears to be sufficiently practical and reliable.

Longitudinal Transverse Collectors and Outlets

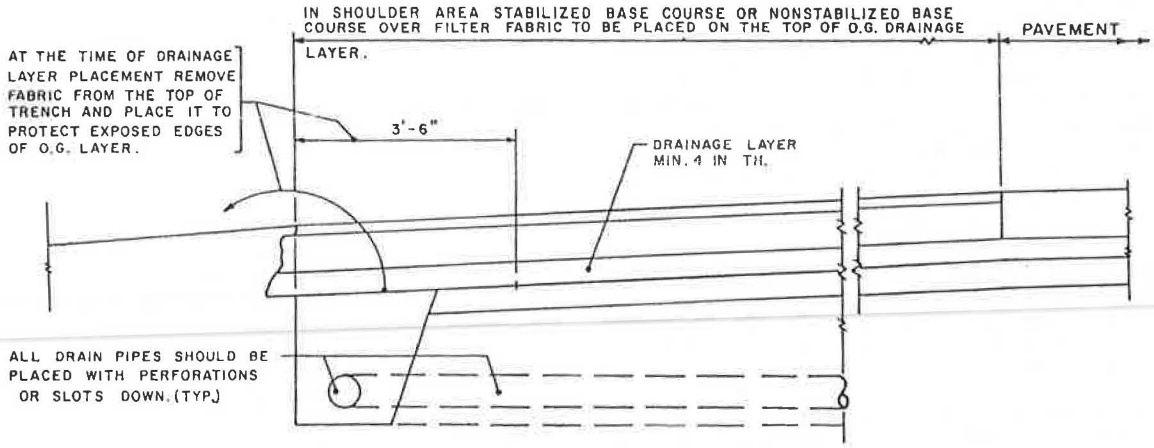
Figures 7-11 provide typical details of longitudinal and transverse collector designs and outlets that are either daylighted or terminated in inlets. Factors that affect collector design basically are



NOTE: 3. FOR ALL TYPES OF PIPES TOTAL MIN. COVER SHALL BE 30 INCHES, BUT NO LESS THAN 12 INCHES OF SOIL SHALL BE PLACED ON TOP OF A PIPE. COMPACTION SHALL BE IN 6 INCH LIFTS BEGINNING WITH FIRST 12 INCHES OF MATERIAL PLACED OVER THE PIPE.

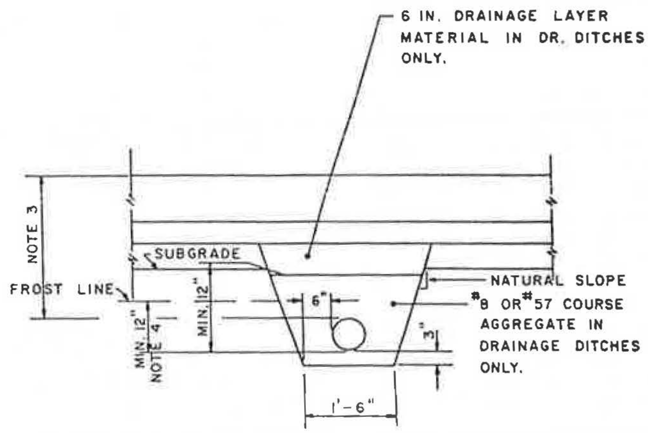
4. IF A SHALLOW COLLECTOR DRAIN IS DESIRED DISREGARD MIN. DEPTH BELOW THE FROST LINE.

FIGURE 7 Typical detail of the edge of pavement subsurface drainage collectors.



NOTE: FOR ALL ADDITIONAL DETAILS AND NOTES SEE FIGURE #7

FIGURE 8 Typical detail of the edge of shoulder subsurface drainage collectors.



NOTE 3 FOR ALL TYPES OF PIPES TOTAL MIN. COVER SHALL BE 30 INCHES, BUT NO LESS THAN 12 INCHES OF SOIL SHALL BE PLACED ON TOP OF A PIPE. COMPACTION SHALL BE IN 6 INCH LIFTS BEGINNING WITH 12 INCHES OF MATERIAL PLACED OVER THE PIPE.

4. IF A SHALLOW COLLECTOR DRAIN IS DESIRED DISREGARD MIN. DEPTH BELOW THE FROST LINE.

FIGURE 9 Typical transverse ditch detail.

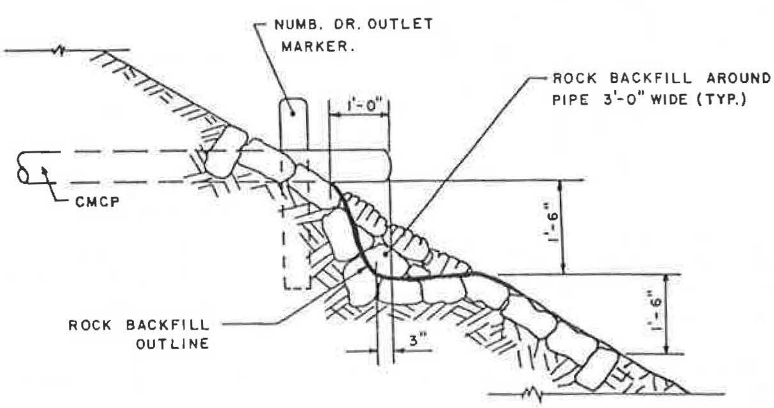


FIGURE 10 Typical detail of drainage outlet with rock backfill.

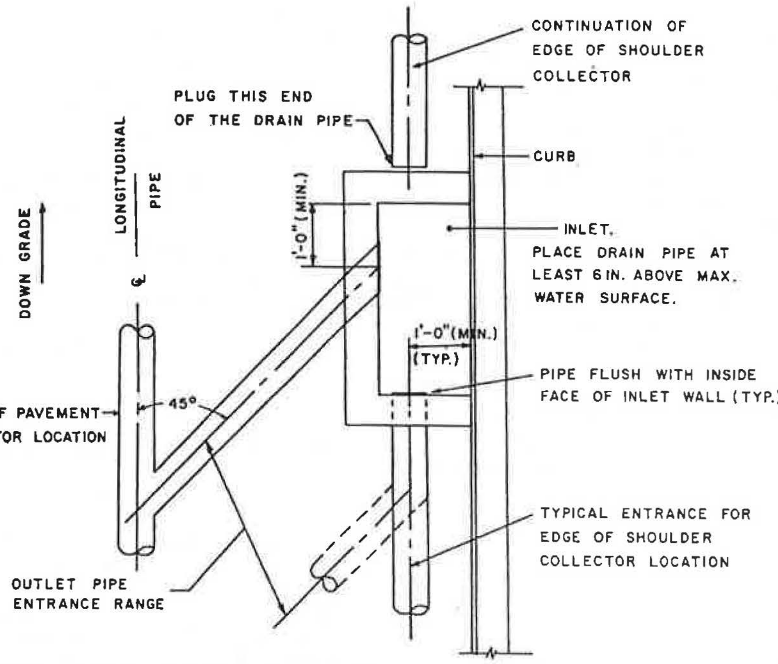


FIGURE 11 Typical outlet pipe entrance detail.

drainability, susceptibility to frost effects, and structural integrity. Drainability is, of course, the purpose of such a system; however, frost or structural instability could jeopardize its functionality. For this reason a collector must be carefully designed and constructed, as shown in Figures 7 and 8. The minimum requirements should be such that a 6-in. clearance is provided between the trench walls and the side of the pipe. In addition, the trench must be deep enough to keep the bottom of the drain pipe on a 3-in. bedding, at least 12 in. below the top of the subgrade, and under minimum structural cover required by the pipe designs.

There appears to be some controversy concerning location of a drain pipe in relation to the frost depth. Theoretically, a functional pipe is not going to have enough water to freeze. However, for reasons not fully substantiated, there are reports of frozen collectors impairing drainage functions. There are enough grounds to believe that situations might arise whereby the function of a collector might be impeded by frost. So the question is, How real a problem is the freezing of a collector system? It is the belief of this researcher that, in lieu of adequate knowledge, the possibility of such a calamity calls for an engineering judgment, and it is suggested that the requirements offered by U.S. Army manual TM5-820-3 (5) and shown in Figures 7-9 be used.

Because a drainage trench is located within a subgrade usually containing a large quantity of fines, a filtration medium such as a filter fabric lining is advisable, especially because the crushed-stone trench backfill must have drainage characteristics exceeding the drainage layer material and particle sizes compatible with the pipe perforations. A No. 8 or No. 57 stone fits well into the situation, whereas the No. 57 and No. 9 mixture has enough No. 9 stone size particles that might easily migrate into the pipe and permanently impede its function. To protect the trench backfill from contamination by fines from adjacent soils, a sufficient length of filter fabric flap should cover the trench during construction. This should be left in place until the placement of the drainage layer, at which time the flap should be removed and placed to protect the edges of drainage material.

The same requirements and procedures are necessary for transverse ditches, except that to increase the structural integrity, the top 6 in. of the pipe backfill is replaced by regular drainage layer material.

As note 3 in Figures 7-9 indicates, porous wall, corrugated metal, and polyvinal chloride (PVC) and polyethylene (PE) plastic pipes can be used in such applications. Although the first two types of pipe material have been used successfully for a long time, the application of plastic materials in such a manner is relatively new.

At this point the importance of only 3 in. of pipe bedding and good compaction of the pipe backfill must be mentioned. Experience has demonstrated that the use of more than 3 in. of bedding provides too much undrainable space below a drain pipe, and the structural strength, especially with plastic pipes, in large measure depends on the proper compaction of the backfill material. Improper handling of either criterion could impede the structural integrity of the collector.

DESIGN OF GROUNDWATER DRAINAGE

The analysis and solutions of the groundwater drainage problems can be found in publications by Moulton (6) and by Kozlov (4).

A groundwater control system refers to subsurface drainage specifically designed to remove or control the flow of groundwater. Such a subsurface drainage system may perform a number of the following functions:

1. Intercept or cut off the seepage above an impervious boundary, and
2. Draw down or lower the water table.

Often such a system may apply to more than one function, such as the interceptor drain not only cuts off the flow but it also draws down the water table. Such subdrainage systems are commonly identified in terms of their location and geometry. Contrary to infiltration water drainage systems, the groundwater drainage system will be used only when and where it is needed. This means it must be designed to fit each case individually, and in most cases it will consist of some form of interceptors. Furthermore, the quantity of flow and the means of its disposal must be known for a groundwater drainage system to be adequately functional.

In most cases little or no water gets into the pavement section from this source. However, in cases of a high water table or artesian flow, the water drawdown that is required often can be accomplished by a properly designed drainage blanket of high permeability. Normally it is located beneath the subbase on the top of the subgrade so as to keep water from saturating the pavement foundation. This layer, in variance to a drainage layer for the removal of roofwater, must be designed and constructed so as to remove all water as soon as it is reasonably possible.

CONSTRUCTION AND MAINTENANCE

General

The limited experience in building internally drainable roads has demonstrated the relatively easy constructability of such systems under portland cement concrete and bituminous concrete pavements. The experience has also revealed the possible pitfalls that can occur when a less-than-concerned attitude exists on the part of the road builders. Attempting to build such systems with inadequate, unsuitable, and dilapidated equipment is bound to be fraught with difficulties. In addition, constructing only part of the underdrainage system and leaving it, for example, over the winter to be completed next spring is totally unacceptable. Even neglecting it during the construction season is extremely ill-advised and will make it prone to considerable damage and probably even early failure at a later date because of possible contamination and degradation. Proper design and strict enforcement of drawings and specifications are absolutely essential. Because such requirements must also apply to the construction of any elements of a highway, the enforcement of said requirements should not cause increased costs when a reputable contractor is involved.

Thus the constructability of BSOG and NSOG drainage layers with proper equipment and in accordance with the procedures appears to cause few, if any, problems. However, if other than the specified equipment and procedures are used, placement of these materials can be somewhat problematic. The performance of such layers under rigid or flexible pavements, when proper confinement is provided, indeed appears to be adequate. When an asphalt-stabilized base is placed over a drainage layer, the BSOG material provides an adequate construction platform, whereas the NSOG layer, under adverse circumstances, might be somewhat unstable. The problems encountered with the NSOG layer appear to occur when adverse construction conditions require an unusual amount of manipulation by trucks delivering the mix to the paver. The end result might be a certain amount of rutting (0.5 to 1.0 in.) of the open-graded layer. If normal rutting is not tolerable, use of the BSOG drainage layer is recommended. However, if the NSOG material is used, careful construction practices (e.g., a laborer with a rake or a small compactor-roller) can keep the surface in an adequate shape.

The best means for including the special underdrainage in roadways is first to construct all subbases. If required, the top of the subbase is then stabilized or the filter cloth barrier is placed to provide a construction platform and to prevent the intrusion of fines into the overlying drainage layer. This is followed by the construction of the collection system. Finally the drainage layer is placed.

Irrespective of the proper design and construction of a subsurface drainage system, some maintenance will be required to ensure the continuous operation of the system. To the extent possible, all features of the system should be designed for minimum maintenance. Nevertheless, a program of continuing regular inspections, preventive-type maintenance, and repair-type maintenance must be anticipated.

Construction of Collection Systems

For drainage trenches the procedure should be to excavate through the subbase to a prescribed depth. Then the trench should be lined with filter cloth by unrolling it by hand, keeping it about 30 ft ahead of the backfilling operation. While two laborers hold the edges, a third man should walk the filter fabric, conforming it to the dimensions of the trench. After that a drainage pipe should be placed on 3 in. of No. 8 stone bedding and backfilled with No. 8 stone. Beginning 12 in. above the top of the pipe, the backfill in the trenches must be compacted in 6-in. lifts by three to four passes of a vibratory plate compactor.

The construction of outlet ditches is similar, except solid (nondrainable) pipes and regular subgrade soils for bedding and the backfill must be used. The outlet pipes should either be daylighted or terminated in the surface drainage inlet structures.

The procedure for trench construction that is acceptable for a small job requires the use of a Grad-All for trench excavation, a front loader for placement of the backfill, and regular trucking for material transportation. Although 1,000 ft per day of such trench construction might be achieved, considerably better progress on the order of 2,000 to 3,000 ft per day should be possible if more appropriate equipment and construction scheduling were used. For example, a significant increase in the efficiency of the trenching operation could be realized if a trenching machine, such as a Ditch Witch, and modified trucks to funnel stone into the ditch were used. All this, coupled with adequately scheduled removal of the excavated material and supply of pipe and backfill, would considerably improve construction progress.

Construction of NSOG and BSOG Drainage Layers

Placement of the open-graded layer (both NSOG and BSOG) can be best accomplished with an asphalt paver. Whether or not a stone spreader for placing an NSOG layer is usable depends on the degree of precision the equipment is capable of; it must be at least equivalent to the precision of an asphalt paver with automatic grade control. For placing NSOG and BSOG materials, the use of a tracked paver is recommended. Additional fine grading with a grader should be nil. Slightly moist (about 2 percent moisture) NSOG material can be handled by an asphalt paver with no modification or damage to the equipment. The NSOG material should be compacted by a vibratory roller, whereas the BSOG layer can be compacted with standard static rollers (three-wheel breakdown roller followed by tandem finishing roller). The vibratory asphalt rollers could possibly be used on the BSOG material, but the temperature would have to be appropriately lower to prevent edge shoving.

Considering that the BSOG mix appears to be somewhat unstable when hot (excessive spreading has been observed at the edges during compaction), it is advisable for compaction to commence at a temperature of about 210°F. For permeability reasons, the mix is rather open with few fines, if any, in it. Thus the asphalt tends to act more as a lubricant, aiding compaction with this mix more than with a dense-graded mixture. The lower compaction temperature permits the asphalt viscosity to increase and its bonding ability to take over to achieve a more stable mix for compaction.

The test strip approach for compaction control of the open-graded layers appears to work well. Because this approach relies only on relative density measurements, a nuclear gauge operated in whatever mode, be it in the backscatter position with or without surface preparation or in the direct transmission mode, should be adequate. A nuclear gauge is thus used to monitor the increasing densities at the same three locations within a control strip between successive roller passes. As the compacted material approaches the maximum density achievable in the field, the average difference between any two consecutive passes approaches zero. Under the direction of the engineer, rolling must continue until this average density difference is less than or equal to 0.5 lb/ft^3. At this point maximum density is inferred because the observed density failed to increase with additional passes. Based on statistical data from the experimental installations, it is expected that most BSOG strips will require approximately 6 passes, and less than 5 percent of the control strip applications should require more than 10 passes. For NSOG control strips the average number of required passes should be approximately five.

As already stated, construction of pavement courses above the open-graded layers should not be difficult if proper equipment is used. After it has cooled, the BSOG material hardens into a very firm layer, which represents an adequate construction platform for both the portland cement and bituminous concrete surfacings. For the NSOG layer, only conventional paving procedures are necessary for placement of the concrete.

No shrinkage cracks in the concrete road slabs and little infiltration of the concrete into the open-graded layers has been observed. The latter case should dispel fears of excessive friction between underlying open-graded material and the pavement slabs.

MAINTENANCE OF SUBSURFACE DRAINAGE SYSTEMS

Irrespective of the proper design and construction of a subsurface drainage system, some maintenance will be required to ensure that the system continues to operate in a satisfactory fashion. In other words, no action or lack of action should be allowed to reduce the efficiency of the system. To the extent possible, all features of the system should be designed for minimum future maintenance. However, every operating condition for the system cannot always be anticipated. Thus a program of continuing regular inspections, preventive-type maintenance, and repair-type maintenance must be anticipated.

Cleaning of Collector Pipes

It might be anticipated that sediment could be deposited in collector pipes because of inadequate pipe gradients, uneven settlement of the system, or a heavy sediment load. In anticipation of such a possibility, clean-out boxes or risers at various locations within the pipe network could be designed into the system and, of course, the pipes also can be cleaned from the outlets. In addition, the pipe network should be designed in such a way that right angle turns are eliminated.

Maintenance of Outlets

The outlet system must be maintained in a free-flow condition throughout the life of the facility. With respect to pipe outlets, the principal concerns would be the blockages caused by weed growth, siltation of the adjacent ditch, debris from the roadway or slope, and activity of animals or man. Only through periodic inspection can these circumstances be identified and subsequently rectified. Such inspections should be made before seasonal periods of heavy rainfall, as well as following particularly heavy rainfall events or at least once every 3 months.

Also, outlet markers should be maintained in good condition. Damaged markers should be repaired or replaced immediately. Any marker destroyed or damaged during other construction or maintenance activities should be immediately reported for replacement or repair.

Miscellaneous Maintenance and Other Considerations

Careful periodic inspections are the key to adequate maintenance of the subsurface drainage system. However, other related maintenance activities associated with the pavement--pavement shoulder, surface drainage system, ice and snow control and removal, right-of-way mowing, and so forth--can all have an impact on the operation and maintenance of the subsurface drainage system. Although the maintenance of the subsurface system might not take precedence over one of the aforementioned activities, it must not be relegated to an insignificant status. For example, although mowing is an essential maintenance activity, it has a potentially detrimental effect on the outlet system. That is, the mowing machines could damage the outlets through impact with the outlets during the mowing operations. If the likelihood of such an occurrence is high, use of erosion control aprons or chemical weed control could be used in lieu of mowing.

Maintenance that ensures the efficient collection and removal of surface water will also generally improve the operation of the subsurface drainage system. Timely repairs of damage to surface drainage structures, pipes, ditches, and so forth will contribute to the proper operation of the subsurface drainage system. Likewise, timely and cautious repairs of damaged pavement and shoulder sections will be beneficial to the underdrain system.

Those responsible for the care of the subsurface drainage systems should maintain detailed as-built plans of the systems to facilitate subsequent repairs and replacements. In addition, a separate record of the location of drainage facilities, particularly outlets, should be maintained so that these facilities can be easily located by maintenance personnel. Inspection records should be kept along with records of each maintenance activity required by the system. If these records are kept in a continuous fashion, they may suggest the need for some more substantial efforts to prevent the recurrence of some continuing maintenance problem. The information concerning the modification of conditions adjacent to the subsurface drainage system must also be diligently gathered and assessed. Any modification or change that would adversely affect the operation of the subsurface drainage system should be corrected promptly to mitigate potentially detrimental effects.

SUBSURFACE DRAINAGE AND PAVEMENT REHABILITATION

Adequate attention should be given to the performance of existing subsurface drainage sytems or to the construction of new or extended systems in conjunction with pavement rehabilitation projects.

Conventional rehabilitation techniques on pavements, where the foundation was undermined by inadequate subsurface drainage, only postpone the inevitable further disintegration of the pavement structure, resulting to a large degree in useless expenditures. Nevertheless, the internal drainage solution was developed for and should be used only for the purpose of resolving internal drainage problems of roads. Therefore, in no way is it just an alternate approach to currently available road pavement designs. Therefore, to assure the resolution of internal drainage on new construction, there is no choice but to apply the methods offered in this paper exclusively; for rehabilitation efforts this solution must be used selectively (i.e., only if road conditions warrant it). It goes without saying that the rehabilitation of roads damaged by other causes than subsurface water should be accordingly performed because their drainage probably already is functional by some natural means, such as permeable enough subgrades.

DESIGN GUIDELINES FOR REHABILITATION OF PAVEMENTS

An effective approach that can be offered for pavement rehabilitation proposes constructing an overlay consisting of 4 in. of BSOG material directly on the existing pavement surfacing and draining it into drainage trenches and outlets, as detailed in this paper. Because of adversities of the construction, NSOG material is not suggested for use in such a rehabilitation effort. The drainage layer, of course, will have to be overlaid by a minimum of 3 in. of bituminous-stabilized base course (BSBC) and 3 in. of medium aggregate bituminous concrete (MABC) surfacing. The proposed solution most probably will mean higher initial cost compared with the present, rather inadequate, conventional rehabilitation methods. This solution, however, appears to be a viable approach to the problems induced by internal drainage because it has the potential for alleviating water-related damage. An illustration of the economic aspects that are involved is available in the NJDOT files (7).

As in the construction of new pavements, the recommended subsurface drains are designed to handle water that infiltrates the pavement area only. It is assumed that the surface drainage is functioning and that the runoff from the surrounding areas will be drained by it.

Where groundwater is an expected problem, an investigation of the water-bearing strata should be made, including depth and permeability of the strata and the amount of water carried by it. This investigation will allow the designer to increase the pipe size to ensure adequate capacities for all sources of water.

CONCLUSIONS

In this paper solutions of the internal drainage problems of roads are provided in a rather condensed (so to speak) "cookbook" form. This became possible only because in this research effort an attempt was made to produce a well-organized, practical, and relatively simple approach to this problem without, however, jeopardizing engineering integrity. Such an approach makes it possible to present an engineer with complete enough procedures for building and maintaining adequately drainable roadways.

In the meantime, future monitoring of the already existing experimental drainable road sections should furnish enough controlled data to detect and, if need be, to remedy deficiencies that might surface.

ACKNOWLEDGMENT

The author is grateful to the personnel of the New Jersey Department of Transportation for their assistance in gathering and evaluating the data necessary for presentation of this paper.

REFERENCES

1. G.S. Kozlov. Road Surface Drainage Design, Construction, and Maintenance Guide for Pavements. New Jersey Department of Transportation, Trenton, June 1981.
2. H.R. Cedergren, K.H. O'Brien, and G.A. Arman. Guidelines for the Design of Subsurface Drainage Systems for Highway Structural Sections. Report FHWA-RD-72-30. FHWA, U.S. Department of Transportation, June 1972.
3. A. Casagrande. Base Course Design for Airport Pavements. Proc., ASCE, Vol. 77, June 1951.
4. G.S. Kozlov. Improved Drainage and Frost Action Criteria for New Jersey Design--Volume III: Road Subsurface Drainage Design, Construction, and Maintenance Guide for Pavements. New Jersey Department of Transportation, Trenton, Aug. 1983.
5. Drainage and Erosion-Control Structures for Airfields and Heliports. Technical Manual TM5-820-3. Department of the Army, Washington, D.C., July 1965.
6. L.K. Moulton. Highway Subdrainage Design. Report FHWA-TS-80-224. FHWA, U.S. Department of Transportation, Aug. 1980.
7. G.S. Kozlov. Rehabilitation of Pavements Damaged by Inadequate Subsurface Road Design. New Jersey Department of Transportation, Trenton, March 1979.

Publication of this paper sponsored by Committee on Subsurface Drainage.