Use of Open-Graded, Free-Draining Layers in Pavement Systems: A National Synthesis Report

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The effects of excessive and uncontrolled water entrapped in the various components of a paving system are known or suspected to have been responsible for unsatisfactory performance and outright failures of both portland cement concrete and asphaltic concrete pavements. To eliminate or at least reduce the detriment, almost half of the highway and transportation agencies across the nation have been addressing the problem by designing and constructing free-draining pavement systems. In an effort to ascertain just how much and what kind of attention is being given free-draining pavements on a national scale and to gain some insight into the performance characteristics of such systems designed to date, the Transportation Research Board's Committee on Subsurface Drainage prepared a questionnaire for national distribution in the fall of 1985. This paper is an attempt to summarize the responses to that questionnaire.

The effects of excessive and uncontrolled water entrapped in the various components of a paving system are known or suspected to have been responsible for unsatisfactory performance and outright failures of both portland cement concrete and asphaltic concrete pavements. In general, the adverse effects are manifested in premature rutting, cracking, faulting, increased roughness, and a relative decrease in the level of serviceability.

For several years, notable highway engineers such as Cedegren, Moulton, and others have advocated pavement designs that emphasize rapid and effective drainage of the pavement structure in order to eliminate or at least reduce the detriment caused by entrapped water. Because it is virtually impossible to keep water out of pavements for anything but a relatively short time and prohibitively expensive to build pavements strong enough to withstand the detriment of entrapped water, almost half of the highway and transportation agencies across the nation have been giving serious attention to the free-draining approach.

In an effort to ascertain just how much and what kind of attention is being given free-draining pavements on a national scale and to gain some insight into the performance characteristics of such systems designed to date, the Transportation Research Board's Committee on Subsurface Drainage prepared a questionnaire for national distribution in the fall of 1985. This paper is an attempt to summarize the response to that questionnaire.

Responses indicated that the term "free-draining pavement system" does not necessarily have the same meaning for everyone.

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In this discussion, a free-draining pavement is one that has been constructed with a full-width open-graded layer somewhere beneath the surface of the pavement but above the subgrade. This layer is normally outlet by some sort of underdrain system or by simply daylighting the free-draining layer to the surface drainage just past the shoulder.

QUESTIONNAIRE RESPONSE

General

Of the 49 agencies that responded to the questionnaire, 25 indicated that they had not used free-draining layers, and 24 indicated that they had used or do use the free-draining concept in their pavement designs. Although there is apparently quite a bit of experimental work still being done with free-draining pavement systems, 15 agencies (or more than 62 percent of those using the concept) indicated that the free-draining approach is being used routinely and that anticipated future use would be on Interstates and high-volume secondary roads.

Response to the question about agency experience (Figure 1) indicated not only that a considerable number of lane miles have been constructed to date by some agencies (one agency reported 1,000 lane miles) but also that some agencies have been working with free-draining pavements for quite some time.

Design and Construction

In theory, the designed thickness of a free-draining pavement layer should be based largely on the amount of expected inflow into the pavement structure. Because most pavement systems are quite dense and, by design, have usually been constructed in an effort to keep water out, infiltration calculations are extremely difficult. Responses to the question about design thickness indicated that a variety of thicknesses of the free-draining layer have been used. The three most popular thicknesses appear to be 6 in. (7 states, 22 percent); 3 in. (3 states, 11 percent); and 12 in. (2 states, 7 percent). The thinnest free-draining layer was reported to be 2 in. and from 18 to 24 in. was reportedly used by one state agency.

The location of the free-draining layer within the pavement structure has been a subject of some controversy. Although cases have been made for putting the free-draining layer between the base and the subgrade, there are apparently equally

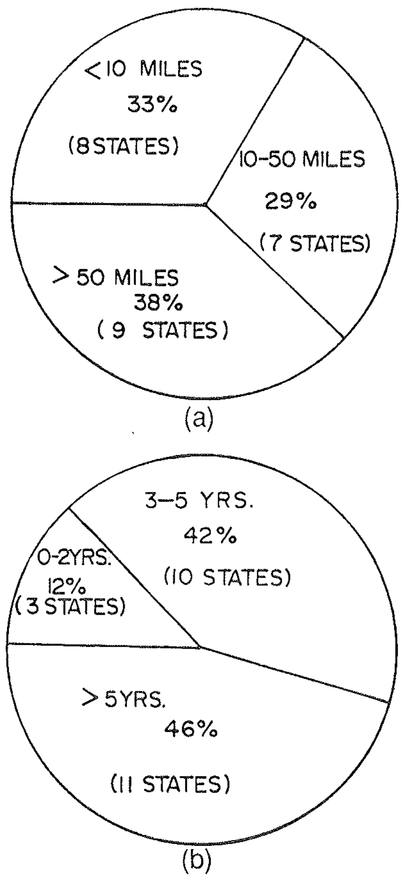

FIGURE 1 Agency experience: *(a)* lane miles of free-draining pavement (percentage of agencies) and *(b)* years of experience with free-draining pavement systems (percentage of agencies).

good reasons for placing the layer immediately beneath the surface of the pavement or in the middle of the pavement structure. Questionnaire responses indicated that the two most popular locations for free-draining layers were between the base and subgrade (44 percent) and immediately below the pavement surface and above the base material (40 percent).

The aggregate gradations specified for use in free-draining layers by responding agencies exhibited quite a bit of variability. Of all of the gradings received, only two were used by more than one responding agency. It is apparent from reviewing gradation specifications that some are considerably more permeable than others. Figure 2 shows the variability in the degree of openness indicated in the responses. (One state reported using 6 to 3/4 in.). Although the goal may be the same, the approach, at least in terms of gradation, is quite different.

Aggregate properties that relate specifically to the permeability or structural stability, or both, of the free-draining layers were of interest. Although the majority of the responses to the aggregate inquiry related more to various quality characteristics such as Los Angeles abrasion and soundness, the single most popular aggregate property listed was face fracture or crushed particle content. Nine states responded that this particular property was important but individually specified crushed particle percentages ranging from 50 to 100 percent. Although the various quality aspects of a particular aggregate can have a bearing on permeability and stability, the only other specified property that appears to be directly related is the coefficient of uniformity (two states).

Stabilization of the free-draining layer solely by compaction appears to be the most popular construction technique. This category received 16 of 29 responses (55 percent) and the next most popular (41 percent) stabilizing technique used bitumen. Completed questionnaires indicated that an approximate average of 2 percent bitumen was used, but actual responses ranged from 2 to 5 percent. Only one response indicated that portland cement was used as a stabilizer and that state reported that they used 282 lb/yd^3 and a 0.37 water-to-cement ratio. Eighty-five percent of all responses indicated that the choice of stabilizer was not optional.

For any free-draining system to be effective, one of the primary requirements is that the free-draining layer be highly permeable. Questionnaire responses concerning permeability indicated that some states are doing better than others with this aspect. Three states responded to the lowest permeability category on the questionnaire (100 to 500 ft/day), and four states responded that permeabilities of from 500 to 1,000 ft/day had been achieved. The majority of the responses (six states or 33 percent) was to the 1,000 to 5,000 ft/day category, and five states responded to the "other" category with one of those states indicating that permeabilities of 10,000 ft/day had been achieved.

The responding state agencies reported several ways in which permeability values were derived. According to the questionnaire responses, falling-head and constant-head measurements were the two most popular methods accounting for nearly 29 percent of the responses each. The only other method used by more than one state was the FPTD, an experimental field instrument developed by Moulton of West Virginia University. Two states indicated that they used the FPTD to make permeability measurements, and one of those states indicated that the permeability exceeded the limits of the device.

Questionnaire responses to the inquiry about compaction of the free-draining layer were for the most part ambiguous. Most states answering this question used phrases such as "to the satisfaction of the engineer" or "enough to seat the stone." No matter how it is accomplished, stabilization is important and has to be given consideration. What might be adequate for a free-draining layer in one location in the pavement system might not be satisfactory in another. The base should be compacted so as to not lose its free-draining character or to the point that the aggregate is crushed. Although generalized compaction requirements may suffice, two states specify a certain percentage of the solid volume density.

Varied responses were given about the type of compaction equipment specified. Most detailed responses indicated that steel-wheeled rollers were used. Those rollers appeared to be generally around 8 tons but ranged from as light as 3 tons to as heavy as 20 tons.

Surface tolerance of the free-draining layer can be an important consideration, especially when different phases of the construction process, involving different materials, are subcontracted to separate contractors. Unless specified grade tolerances can be maintained, significant problems with quantities can arise. There were more responses (five states) indicating a

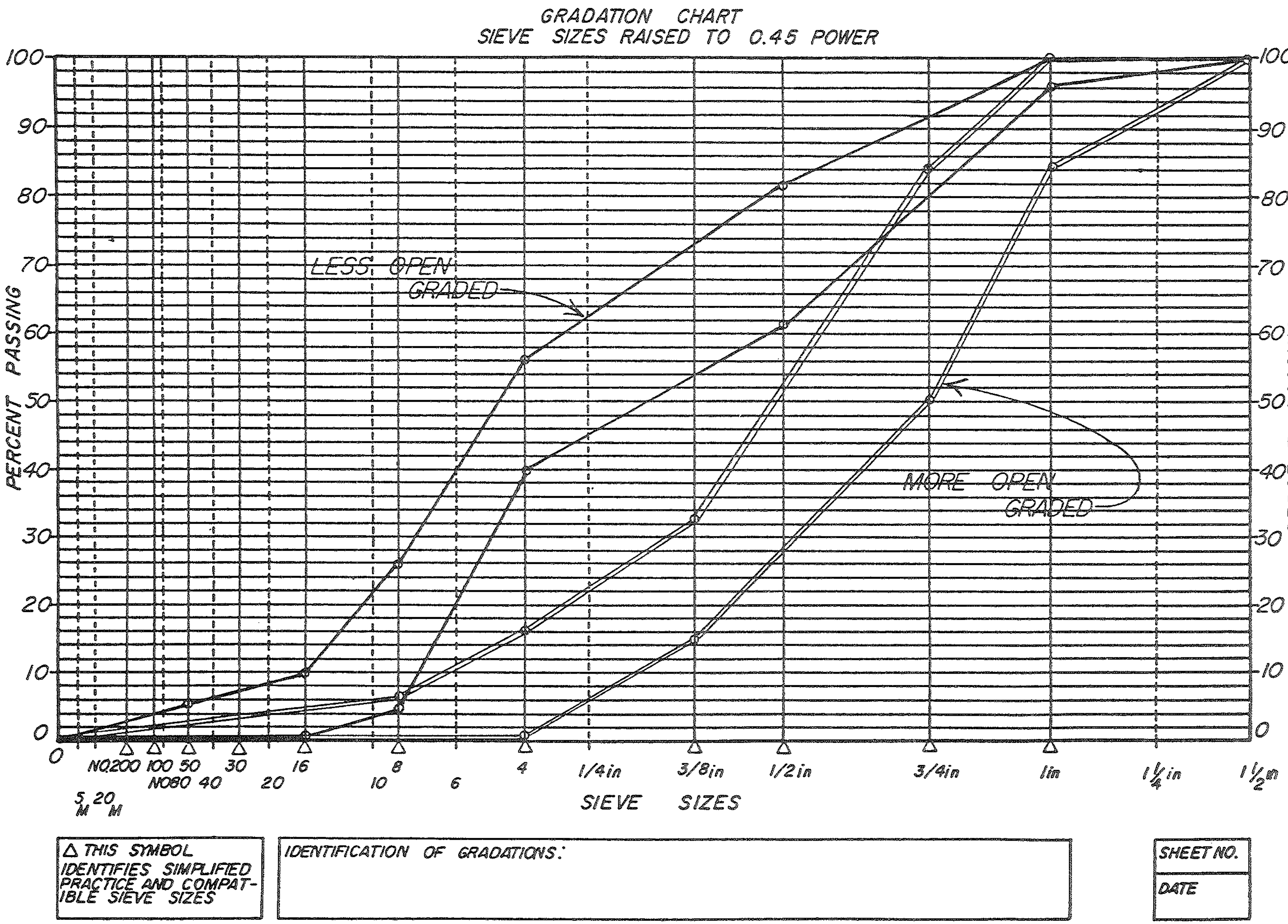

FIGURE 2 Variability in degree of openness indicated in responses.

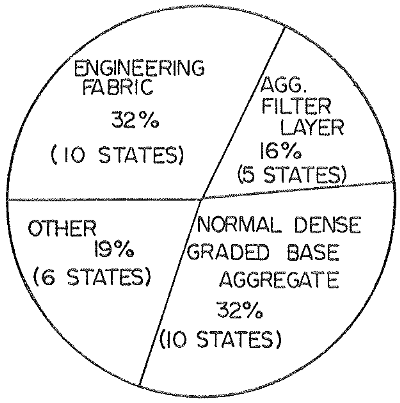

FIGURE 3 Protection of free-draining layer against intrusion of fine particles.

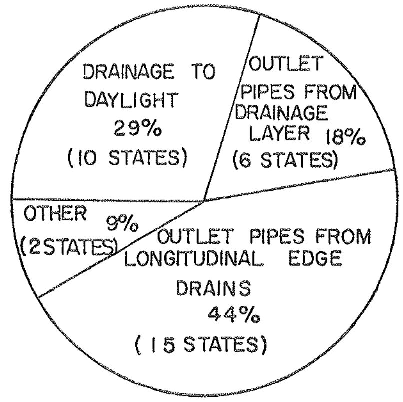

FIGURE 4 Outletting water.

± 0.25-in. tolerance than any other. All other tolerances specified were greater than 1/4 in., and two states allow as much as ± 1.2 in.

The next questionnaire inquiry involved structural determinations and the assigning of structural values to free-draining layers. Forty-seven percent of the responses indicated that a structural value of 0.14 was used for the free-draining layer. No other single value reported was used by more than one state. Those values ranged from 0.08 to 0.80 and, except for a few ambiguous answers, no two states agreed on the method of determining the value assigned.

Protection of the open-graded layer against the intrusion of fine particles is worthy of special consideration if that layer is to function as intended for the normal design life of the pavement. As is evident in Figure 3, as many states are using engineering fabric for this application as consider the normal dense-graded base aggregate sufficient.

Getting the water out of the drainage layer and away from the pavement is critical to satisfactory performance. As shown in Figure 4, there are three basic methods that have been used by the responding states to accomplish this.

The appropriate spacing between outlets is highly dependent on the amount of inflow into the pavement system, which is influenced in part by the amount and duration of rainfall. When the variety of climatic conditions associated with the different regions of the United States is considered, it is not surprising to find a variety of responses to the inquiry about outlet spacing. Three states (17 percent) indicated that spacing intervals of 500 ft were used, and four states (22 percent) indicated that a 300-ft spacing was used. All other responses were unique and ranged from as close as 100 ft to as far as 1,500 ft per outlet.

Ten state agencies or 43 percent of the responses indicated that their outlet spacing is determined by hydraulic design, and six agencies or 26 percent of the respondents used standard (state) specifications. All other responses (seven) were too generalized to be definitive.

Protection of the outlets through which water exits the system is an important consideration. No matter how adequately a free-draining system is designed, if the outlets become restricted or blocked, the effectiveness of the entire system could be eliminated. This could lead to problems even greater than those that free-draining pavements are designed to correct. One of the more effective protective measures would appear to be the construction of concrete headwalls, an approach indicated by 50 percent of the responding state agencies. One of these agencies indicated that they went one step further by including bars, presumably to prohibit animals from nesting within the outlet. One other state used rock backfill around the outlet, and most of the remaining responses had to do with using markers to identify where the outlets were located or using grates or flaps on the outlets.

Because of the physical characteristics of most free-draining pavement layers, a little more care or caution needs to be exercised during construction in order to meet grade tolerances and to keep the material free draining. According to the questionnaire responses, shoving or rutting of the free-draining layer during construction is the single most troublesome problem as indicated by 35 percent of the responses (eight states). The only other problem common to more than one state (three states or 13 percent of responses) has to do with maintaining traffic during construction of the free-draining layer. The remaining 12 states (52 percent of responding agencies) indicated varied individual problems not shared or indicated by any other state. These problems ranged from problems with the overdensification of the material to problems with meeting the grade tolerance of the layer.

SUMMARY

In an effort to prolong pavement life, a significant number of highway agencies across the nation are taking positive steps to provide rapid internal drainage of their pavements through the incorporation of a free-draining layer. Although several states are still experimenting, the majority of the states that have tried the free-draining approach are now using the concept routinely in pavement design.

As is evident from the responses to this questionnaire, there is considerable variability in design of free-draining pavements among the various states. Because of the relative newness of most of the free-drainage projects constructed nationally, a valid overall performance evaluation or assessment may not be possible for a number of years. On the sole basis of performance to date of such pavement systems, however, the overwhelming majority (78 percent) of the respondents rated their systems as either excellent or good.

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