Design, Construction, and Evaluation of West Virginia's First Free-Draining Pavement System

JOHN S. BALDWIN AND DONALD C. LONG

The adverse effects of entrapped water within the various components of a pavement system are generally accepted and well-known. In an effort to reduce, if not eliminate, the detriment of the entrapped water, the West Virginia Department of Highways constructed its first project using the free-draining concept in the summer of 1982. The project chosen for experimentation involved over 5 mi of four-lane divided highway. Incorporated in this full-depth asphaltic pavement is a 4-in. bituminous, stabilized, open-graded base course which is connected to the surface drainage by numerous aggregate-filled fabric underdrains. This paper discusses the design considerations given this project, the construction sequence used, and the evaluation of the pavement system after 4.5 yr of service.

It is now generally accepted in West Virginia, as in many other states, that excessive and uncontrolled water entrapped within the components of a traditionally designed pavement system will eventually lead to pavement distress. In an effort to reduce, if not eliminate, the detriment of the entrapped water, the West Virginia Department of Highways constructed its first project using the free-draining approach during the summer of 1982. The project was on an Appalachian Development Corridor and involved a 5.2-mi section of four-lane divided highway.

The project chosen for experimentation had been designed for a 10-in. portland cement concrete pavement over a dense 6-in. crushed aggregate base course which in turn overlaid a dense 6-in. granular subgrade.

Construction had been completed to the top of the subgrade layer when it was decided to redesign the project to permit bidding on equal alternate pavement systems consisting of either full-depth asphaltic concrete or portland cement concrete. Both of the alternate systems were to incorporate a free-draining layer.

DESIGN

When consideration was given to using a free-draining layer, the first question to arise involved the gradation of the aggregate. It seemed apparent that a reasonable balance between drainability and stability would be necessary because optimum permeability and good stability tend to be opposing factors. If consideration had to be given only to the drainage aspect, round particles of a single size would appear to be the best suited, but there would be little strength or stability in such a material. Conversely, a very dense and stable material would most likely lead to poor drainage characteristics. Based on previous but limited experience, an AASHTO 57 gradation appeared to be well suited, especially because a standard gradation was desirable. That particular gradation exhibited a satisfactory interconnected void space while at the same time appeared to have reasonably good interlock between particles for stability. In order to enhance the stability, especially during the construction phase, it was decided to add 2 percent bituminous material to the aggregate, which was expected to be just enough to completely coat each individual particle and bind the mass together.

Where a free-draining layer should be placed in a pavement structure is a subject of some debate. There appear to be legitimate and compelling reasons for locating the layer at the bottom of the pavement structure as well as at the top or somewhere in between (*1*). Weighing the advantages and disadvantages of each pavement configuration, it was decided to place the free-draining layer as a base course at the bottom of the pavement structure in the hope that, by doing so, a greater thickness of the pavement structure could be kept free from water accumulation.

Ideally, the thickness of a free-draining layer should be based on the amount of expected inflow into the pavement system. Calculating that inflow, however, proved to be a difficult task because West Virginia's conventional pavements are designed to keep as much water out of the pavement system as possible. Based on engineering judgment and the moderate levels of rainfall encountered throughout the state, a 4-in.-thick free-draining layer was believed to be adequate.

There appeared to be two options possible for removing the water from the free-draining layer: either concentrate the drainage and channel it into controlled outlet points or "daylight" the free-draining layer into the surface drainage. Although both concepts have been used in West Virginia since the first free-draining project was constructed, the initial project used the controlled outlet approach. In this project, water is directed toward a "V" ditch which was constructed parallel to the alignment of the roadway underneath the shoulder. At 100-ft intervals, aggregate filled underdrains intersect the "V" ditch, thus allowing the water an easy flow path to the surface drainage.

West Virginia Department of Highways, Materials Control, Soils and Testing Division, 312 Michigan Avenue, Charleston, W. Va. 25311.

The only other aspect of the free-draining layer that needed to be addressed before commencing such a project was how to protect the free-draining base from clogging. The gradation of the granular subgrade was such that standard filter calculations indicated the need for a filter between the subgrade and the free-draining base. Again, alternates were permitted in the contract. Either an appropriate geotextile filter or a 2-in. layer of filter aggregate was permissible.

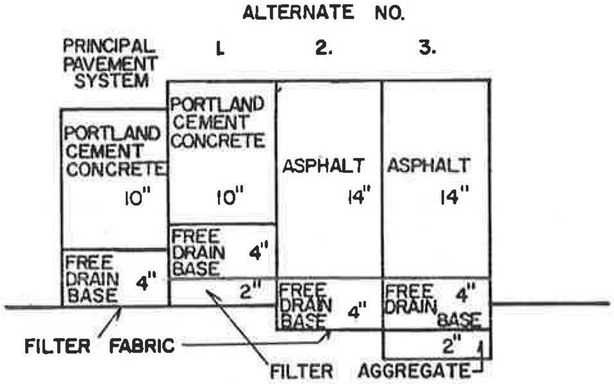

FIGURE 1 **Alternate free-draining pavement designs.**

The project was advertised with four alternates (Figure 1)—two for the portland cement concrete pavement and two for the full-depth asphalt. The successful contractor chose the full-depth asphalt with the filter fabric alternate. In cross section it appeared as shown in Figure 2. As is evident in the drawing, the fabric wrapped over the top of the free-draining base to protect against the infiltration of fines from the overlying shoulder stone.

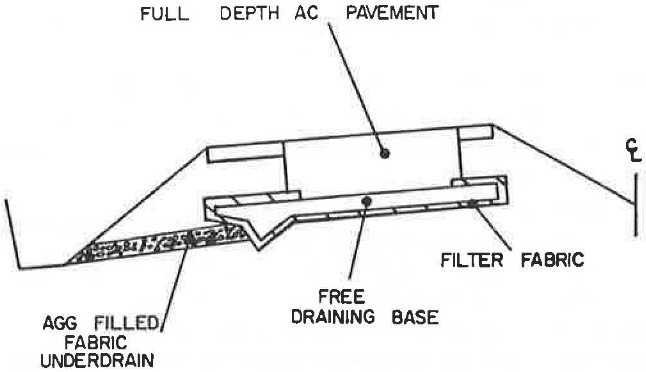

FIGURE 2 **Free-draining pavement in cross section.**

CONSTRUCTION

Work was begun on the project on June 30, 1982. The first order of business was to shape the existing subgrade to template. That required removal of approximately 2 in. of the existing granular subgrade and included the excavation of the lateral "V" ditch.

Next, the contractor installed the aggregate-filled fabric underdrains. He cut a narrow trench into the subgrade of the shoulder at a 45 degree downgrade angle to the roadway alignment. The trenches were then lined with engineering fabric and backfilled with uncrushed pea gravel as shown in Figures 3 and 4. Underdrains were generally constructed at 100-ft intervals.

FIGURE 3 **Cutting of the underdrain trenches.**

FIGURE 4 **Installation of the aggregate-filled fabric underdrains.**

The next phase was to place the geotextile filter over the subgrade as shown in Figure 5. The geotextile filter covered the entire main alignment of the roadway and extended far enough laterally to completely line the lateral "V" ditch. Where the aggregate-filled fabric underdrains intersected the "V" ditch, a piece was cut from the fabric in the ditch. The fabric from the underdrain was then pulled through and laid open to provide direct contact between the pea gravel and the free-draining material which was to be subsequently placed.

As shown in Figure 6, the "V" ditch was the first area to receive the free-draining base. This had been a matter of some concern. Some contractors had expressed doubt that reasonable stability could be achieved where the material was placed this thick (up to 16 in.). It was placed in a single lift with a side paver. The placement occurred essentially without incident and instability was never a problem.

FIGURE 5 Geotextile filter placement.

FIGURE 6 Filling of the "V" ditch with free-draining base.

Once the "V" ditch had been filled and compacted enough to seat the stone, placement and rolling of the 4 in. of free-draining base on the main alignment of the roadway was accomplished. This was also done without any significant problems, although maneuvering the paving machine and trucks directly on top of the geotextile occasionally resulted in some tearing of the fabric which had to be patched.

As was found from working with free-draining bases on subsequent projects, a large part of a successful installation is based on allowing the placed material to cool to approximately 130°F to 150°F before rolling is attempted.

Subsequent operations that involved placing additional lifts of full-depth asphaltic pavement (for a total of 14 additional in.) also proceeded smoothly with the free-draining base apparently providing ample support. Figure 7 shows a cross section of the pavement structure under construction.

PERFORMANCE AND EVALUATION

In order to judge the effectiveness of any free-draining pavement system, it is apparent that four factors would have to be determined over a period of time:

- Amount of inflow into the pavement system,
- Amount of outflow from the pavement system,
- Amount of time necessary to rid the pavement system of intrusive water, and
- Durability of the pavement as compared to conventionally designed pavements.

FIGURE 7 Cross section of pavement under construction.

Although there was definite interest in how well this project performed as a whole, it was obvious from the length of this roadway (5.2 mi) that specific test sections would have to be defined in order to meet the objectives of the performance evaluation. Consequently, four test sections were chosen for experimentation and close monitoring.

Rather than base the evaluation of this free-draining system on obscure calculations, it was decided to attempt to periodically control the input of water into the system via borings in the pavement in each of the test sections and measure outflow versus time. It was also decided that perhaps the best way to determine whether the system was performing as intended was to install cased observation borings into the pavement structure, especially at the bottom of vertical curves. With the project equipped with an automatic rain gauge to quantify rainfall events, plans were made to periodically uncap these observation wells during or immediately after inclement periods to check for water buildup within the system.

In order to get an overview of the effectiveness of the entire project, comprehensive drainage adequacy surveys, coupled with informal pavement condition surveys, were planned to take place annually. These surveys were to provide information concerning the condition or adequacy of each individual drain in the experimental system as well as to provide an indication of the overall appearance and rideability of the pavement.

Water Injection Tests

Throughout the 3-yr evaluation period, controlled input and outflow measurements were made at each of the four pavement sections chosen for monitoring. Basically, the tests consisted of introducing metered water from a 400-gal water vessel, at a measured flow rate, into the 4-in.-diameter injection wells which extended vertically to the bottom of the free-draining base. All injection wells were located so that the water had to drain through both traffic lanes before exiting through the drainage outlets. The amount of time required to obtain flow from the applicable drain outlets was measured as were the outflow volumes which were experienced through the duration of the tests. Input into the system was generally discontinued when a constant outflow was achieved, but timed outflow measurements were continued until outflow essentially stopped.

A variety of input, outflow, and time measurements were recorded at each of the test sections over the 3-yr monitoring period. The primary influence on how fast water could purposely be introduced into the system appeared to be based on the maximum outflow capability of the vessel used to transport water to the project (6 gal/min) and on the amount of particulate matter (road dust, fine cinders, etc.) that fell into the wells from around the embedded well caps each time they were opened for testing or observation. In the beginning, newly drilled injection wells appeared to easily take on the maximum 6 gal of water per min that was available for input. In fact, there were indications that a much greater timed volume could have been introduced if it were available. In time, however, with the cumulative addition of particulate matter, a substantial reduction in the amount of water that could be introduced into those same wells was experienced.

The particulate contamination appeared to restrict the flow only in the well, however, because replacement wells, installed adjacent to those exhibiting reduced flow, revealed no problem in accepting the maximum 6 gal/min input.

Measurement of the outflow from the system revealed that as little as 9 percent to as much as 100 percent of the water purposely introduced was recovered, but this should not be taken as an accurate indication of efficiency. In most cases, those measurements were heavily influenced by how effective the attempts were in inducing positive flow from the actual outlets in the test sections. Not only were the aggregate filled underdrains capable of passing water into the soil at virtually any point along their length, but the biggest problem involved accurately measuring the outflow from them. Initial attempts to raise the fabric outlet high enough to measure the outflow failed because the water simply flowed through the permeable fabric liner at the first point where the fabric left the soil. Pieces of "U" shaped steel guard rail were driven back under the drain outlets in an attempt to provide a more positive impermeable channel through which the water could flow.

Visual observations of flow activity at the outlets as well as from within the pavement and "V" ditch observation wells indicated that essentially all the water introduced directly into the pavement system had passed completely through the system (including the appropriate outlets) in no more than 4 hr from when the water was injected. The time necessary to rid the actual pavement structure of the water was undoubtedly less.

Inclement Weather Observations

One of the primary objectives of the evaluation was to observe the project during or shortly after rainfall events. Throughout the course of the 3-yr monitoring program, those objectives were met on numerous occasions, but because of the magnitude of the project, the majority of those observations were confined to the observation wells and underdrain outlets associated with the four test sections previously described.

According to rain gauge data, the performance of the project was observed during inclement periods that yielded as little as 0.11 in. of rain in 5 hr to as much as 1.79 in. in 20 hr. Individual underdrain outflow measurements made during these events indicated a range in flow rate from as little as one drop per sec to as much as 3.75 gal/min.

Of all the inclement weather observations made, the earliest and perhaps most dramatic observation occurred on May 4, 1983. Although it was not raining at the time the project was inspected, rain gauge charts indicated that 1.79 in. of steady rainfall had fallen on the project in the previous 20-hr period. Arrival at the project was at 9:00 a.m. and, according to the rain gauge data, the storm had slacked off and ended at around 5:00 a.m. that morning.

Observed outflow from all underdrains observed was impressive. In order to quantify the visual observations, measurements of outflow were made at the four defined test sections. Flow rates from 1.25 gal/min to as much as 3.75 gal/min were recorded within 1 hr after arrival (5 hr after rainfall had essentially ended).

Immediately after each test section outflow measurement was made, the associated wells in the free-draining base underlying the pavement, as well as those installed in the "V" ditch, were uncapped. Although all observation wells into the free-draining base were moist, no measurable water was observed. This indicated that the water had at least exited the main pavement structure. Conversely, measurable water (up to 7 in.) was found in some of the "V" ditch observation wells which decreased throughout the day.

Observations made on October 20, 1983, indicated that neither a large quantity of rainfall nor a buildup of measurable water within the "V" ditch was necessary before outflow occurred. Measurements of outflow collected that day revealed that flow rates as high as 0.18 gal/min were possible with only 0.11 in. of rainfall. Rain gauge data indicated that the 0.11 in. had accumulated in 5 hr, before the outflow measurement, and that no precipitation had fallen in the previous 24-hr period. While outflow rates increased as precipitation continued, measurable water was never found in any of the observation wells even though 0.44 in. of rain had fallen when the observations were discontinued.

Although the minimum amount of rainfall necessary to induce outflow has not been determined, it is believed that such quantification would be meaningless because of the numerous interrelated factors which would undoubtedly have a bearing on such measurements. Some of those factors include rainfall intensity, rainfall duration, temperature, humidity, the amount of previous rainfall, and the permeability or porosity of the pavement components.

In addition to obtaining actual outflow measurements, an attempt was made to visually inspect some of the other underdrains in the system. The inspection of those outlets that were found generally revealed good outflow. Many of the actual outlets, however, could not be positively located; but overly saturated soil at 100-ft intervals, adjacent to the shoulder, was often apparent. This was indicative that water was indeed exiting the system at most of the outlet points as intended.

Field Permeability Testing

It was obvious from outflow measurements collected during inclement periods that substantial volumes of water were infiltrating into the pavement system. While available literature indicates that water can infiltrate a pavement system from under the pavement or laterally from the sides or shoulders of a pavement, popular consensus is that the primary source of intrusive water that enters a pavement is from the pavement surface (2). Although this consensus is undoubtedly based on the assumption that most pavements contain cracks and joints, the permeability of the paving materials also appears to be taken into consideration. While this pavement had no joints or obvious cracks, an attempt was made to quantify water infiltration into the pavement system through permeability measurements of the pavement surface.

The device used to make the permeability measurements was an outflow meter. Although this device was originally designed to determine the macro texture of a pavement surface, the theory of operation was very similar to falling head permeability devices used in the laboratory.

The outflow meter is a Plexiglas™ cylinder, sealed at one end by a removable plunger. Attached to the inside of the cylinder at precise intervals are three electrodes that are interconnected to a digital stopwatch. The electrodes activate the stopwatch and stop it with the passing of a predetermined volume of water, thus making it possible to accurately determine the outflow from the device after raising the plunger. Assuming a watertight seal could be made and maintained between the circumference of the base of the unit and the surface of the pavement, the rate of outflow from the device would be directly proportional to the rate of inflow into the pavement.

During the construction of this project the outflow meter was used in conjunction with the free-draining base. That testing indicated that the free-draining layer was effective in passing at least 27 gal of water per square foot of surface per min. Attempts to obtain permeability values for the wearing surface indicated that material was essentially nonpermeable. Permeability testing of the asphaltic shoulder material was also attempted but was not successful because of failure to get a watertight seal between the base of the device and the shoulder material itself.

Assuming that the technique used in making the permeability determinations was valid, at least from the comparative standpoint, the pavement surface in this particular project is not believed to be the primary source for water that infiltrates into the pavement structure. The absorption of water by the shoulder material observed during this and other testing has led to the suspicion that the shoulder areas might be the primary source of infiltration.

Drainage Surveys

One of the priorities in evaluating the effectiveness of this free-draining system was to formally survey the drainage performance of each of the underdrain outlets. This was accomplished in the spring of each of the 3 yr of the monitoring period and turned out to be a much more arduous task than originally envisioned. Because of a successful seeding operation and because the length of the underdrains varied considerably, it was increasingly difficult to locate the individual drain outlets even though they were constructed on 100-ft centers. In addition, once drain outlets were located, it was difficult to evaluate their individual effectiveness uniformly because the performance level of the drains was not the same. This may have been caused, in part, by the intermittent precipitation rates that occurred during the survey periods or by the amount of water passing through the system that was available for outletting from one location to another.

In order to simplify the evaluation process, the following categories of drain adequacy were defined and used:

- Open and flowing or shows evidence of flow,
- Open and moist,
- Open,
- Covered but flowing or shows evidence of flow,
- Covered but moist, and
- Completely covered, blocked, or too low for effective drainage.

Without knowing anything else about the individual drains other than the condition of the outlets themselves, the first four categories were thought to indicate satisfactory performance, even though direct observation of flow was not always discernible. The condition associated with the last two categories was believed detrimental enough that drainage could not be considered adequate, at least for the rapid removal of water.

The summary of the drainage for the entire project is graphically shown in Figure 8. The bars depicted in the graph represent the drain adequacy for all drain outlets as surveyed in 1983, 1984, and 1985. Each total bar represents the percentage of the outlets actually found throughout the 5-mi project in each of the surveys. As shown, more of the drain outlets (60 percent) were found in the first year of the survey than in either of the subsequent survey years. The shaded portion of each bar represents the percentage of all the outlets in the project that

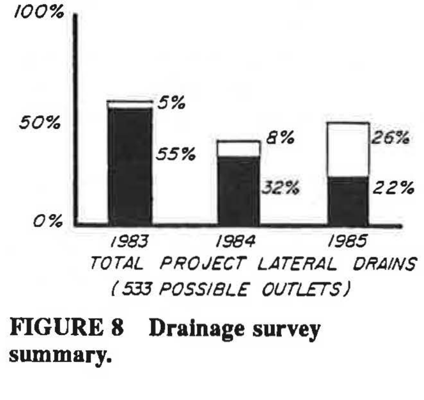

FIGURE 8 Drainage survey summary.

were found and judged to be capable of rapidly removing water from the pavement system. The unshaded area represents the percentage of outlets judged not to be performing satisfactorily. Overall, the surveys indicate a trend of decreasing effectiveness for rapidly outletting the water.

Pavement Appearance

Although the overall general appearance and rideability of this pavement is still relatively good after 4.5 yr of service, a gradual but noticeable decline in both pavement properties has been observed. This decline is attributed to two basic pavement problems, neither of which has been found to be related to the performance of the free-draining layer.

The first surface anomaly noticed affected mostly the rideability of the pavement. It involved the early occurrence of several transverse depressions which were apparent throughout the project. These depressions were primarily the result of differential settlement of the poorly compacted backfill associated with underlying transverse pipe.

The most noticeable surface anomaly that affected the appearance of the pavement was the occurrence of longitudinal cracks in the surface of the pavement. These cracks were prominent in several areas of the project and were mostly confined to the wheel paths of the outside lane as is shown in Figure 9.

FIGURE 9 Longitudinal surface cracking.

In 1986, several of the areas exhibiting the longitudinal cracks were core drilled. Examination of the cores indicated that the fractures generally extended only through the top inch of the wearing surface. The probable cause of the fractures has been attributed to an excessively hot liquid asphalt which was used in the batching of the wearing course. Consequently, this resulted in a thin coating of the aggregate particles and a relatively brittle mix.

Only slight rutting of the pavement surface has been observed. The wheel track rut depth has been measured on more than one occasion and was found to be comparable to other bituminous pavements of similar age and traffic.

CONCLUSIONS

The concept of using a drainage layer in pavement systems appears to be a worthwhile venture. Assuming that the effect of free water in conventional pavements is the major problem that it is widely reported to be, the 4.5 yr experience with West Virginia's first free-draining project would indicate that the use of a drainage layer can be effective in ridding pavement components of water buildup. Even though measurable free water has been documented in the subpavement collection trenches (located at the edge of the pavement), water has never been found to accumulate in the free-draining base within the actual pavement structure itself.

The most effective method of outletting the water from the pavement is still undecided. West Virginia's original free-draining project, which used a subpavement "V" shaped collection ditch coupled with aggregate filled engineering fabric underdrains, is continuing to be effective, but the increasing number of underdrain outlets that appear to be becoming clogged or blocked on that project is a source of concern. Even though the number of apparently inoperable drain outlets is now substantial, more underdrains were installed on this project than are probably necessary. Also, when considering those outlets deemed nonadequate, it should be kept in mind that water can and undoubtedly does pass through—even if not as rapidly and freely as would be desired.

Although it is apparent that West Virginia's first free-draining pavement is performing as intended, it is concluded from the experience gained from monitoring this project that the continued effectiveness could have been better ensured if a more positive and protected means of outletting water from the system had been employed. Recently constructed drainage projects in West Virginia have used corrugated plastic pipe with a protective concrete headwall at the outlet opening. Those installations appear to be more promising. Additionally, it is believed that providing greater vertical relief between the outlet opening and the surface drainage would help keep more of the underdrain outlets open and free flowing.

With these factors in mind, other systems of outletting the water from the free-draining layer have been designed and constructed on subsequent free-draining pavement projects in West Virginia. These systems will be monitored in the future to determine which type provides optimum performance.

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Publication of this paper sponsored by Committee on Subsurface Drainage.