Prefabricated Pavement Base Drain

KEITH L. HIGHLANDS, ROBERT TURGEON, AND GARY L. HOFFMAN

The objective of this research project is to evaluate and compare the construction, effectiveness, and cost of a geocomposite prefabricated pavement edge-drain system versus the Pennsylvania Department of Transportation (PennDOT) standard geotextile-wrapped, aggregate and pipe, filled trench pavement base drain system. Generally, PennDOT's standard edge drain appeared to outperform the geocomposite edge drain. Although the flow data collected were inadequate to be conclusive, the flows measured from the geocomposite edge drain were consistently less than the flows measured from PennDOT's standard edge-drain system. Upon investigation by excavation, areas were found where the geocomposite edge-drain core was clogged with fines. A gradation analysis indicated that PennDOT's standard edge-drain system was not significantly infiltrated by fine soil particles from the base or subgrade. The geocomposite properties were inadequate either to prevent fine soil particles from entering the core or to expel the fines from the system after they had entered the core. The conclusion is that the prefabricated geocomposite was inappropriately used on a site where severe dynamic conditions precluded its proper function. Consequently, more restrictive product properties or application criteria need to be developed to ensure future success under similar field conditions.

The objective of this study is to evaluate and compare the construction, effectiveness, and cost of a prefabricated pavement base drain versus the standard pavement base drain system of the Pennsylvania Department of Transportation (PennDOT). There were three experimental installation sites of prefabricated pavement base drain on this research project. This paper details the evaluation at the first site constructed, located on Interstate Highway 70 in Washington County. For approximately 19 mi of roadway, prefabricated pavement base drain was installed along the westbound lanes and PennDOT's standard pavement base drain system was installed along the eastbound lanes. The prefabricated and standard pavement base drain systems were installed as part of a highway rehabilitation project during summer and fall 1984.

CONSTRUCTION

From July to November 1984, 21,481 linear ft (L.F.) of PennDOT's standard pavement base drain and 20,223 L.F. of geocomposite prefabricated pavement base drain were installed at this research site. A detailed description of the sequence of construction operations, as well as construction problems encountered related to the pavement base drain system installation, may be found in the Construction Report (*1*).

The bid price was $5.50/L.F. for PennDOT's standard pavement base drain and $3.70/L.F. for the prefabricated pavement base drain.

Bureau of Bridge and Roadway Technology, Pennsylvania Department of Transportation, Harrisburg, Pa. 17120.

POSTCONSTRUCTION TESTING AND EVALUATION

Following installation, the flow carried by each of the pavement base drain systems was measured during a 3 year period. The project site was also periodically inspected to identify any pavement or shoulder distress related to the construction or performance of the drainage systems.

The flow was monitored along the westbound and eastbound lanes with tipping buckets. The sites selected for installation of the tipping buckets were generally similar. Similar sites were selected to allow a relatively equal direct comparison of the flows measured by the tipping buckets. Approximately 500 ft of prefabricated pavement base drain led to the outlet that emptied into the tipping bucket along the westbound lanes, and 500 ft of PennDOT's standard pavement base drain led to the outlet that emptied into the tipping bucket along the eastbound lanes. The highway grade along the two sections of drainage that led to the tipping buckets also appeared similar.

The flow data collected generally indicated that slightly more than one to three times more water consistently flowed from the standard pavement base drain system along the eastbound lanes than from the prefabricated pavement base drain along the westbound lanes. Exact flow rates cannot be calculated from these data because the flows were not constant or continuous. The data are contradictory to flow comparisons made by a number of other state DOTs whose standard pipe-and-backfill systems use sand as the backfill material. The AASHTO No. 8 aggregate backfill in PennDOT's standard system allows higher flows, but this set of data was gathered during a brief period of time and should not be given too much importance.

The project site was periodically inspected to identify any pavement or shoulder distress related to the construction or performance of the drainage systems. One of the first problems observed was subsidence of the prefabricated pavement base drain. This subsidence was most likely a result of inadequate trench backfill compaction. The importance of properly compacting trench backfill is discussed in the previous section.

Since the 1984 rehabilitation, several pavement areas along this 5-mi roadway section have exhibited distress. By mid-1988, fines on the roadway shoulder indicated that extensive pumping had occurred in several areas of this research project site. Subjectively, it appeared that more pumping had occurred along the westbound lanes. The extensive pumping raised questions as to how well the pavement base drain systems were performing. In July 1987, a borescope inspection into the internal core of the prefabricated pavement base drain installed near the western end of this project had revealed that the core was not clogged and was carrying water in a

particular area examined near the western end of the project. However, no pumping was observed along the roadway in the area where the July 1987 borescopings were done, so this inspection gave no real assurance that problems did not exist with the pavement base drain where the pumping was occurring. It was decided that portions of the pavement base drain systems should be excavated and examined to identify how their performance may have influenced the pumping observed in other areas along the research project site.

On June 10, 1988, personnel from the Bureau of Bridge and Roadway Technology (BART) and PennDOT Engineering District 12-0, Design and Maintenance, inspected the site conditions. The Assistant County Maintenance Manager pointed out problem areas and described site conditions. He said that his crews had found wet, muddy material under slabs when they made repairs.

In several areas during the June 10, 1988, inspection, the westbound and eastbound roadway shoulders were stained with fine material pumped from under the pavement. Considering these observations, three locations were selected for excavation of prefabricated pavement base drain and standard pavement base drain materials to determine their possible influence on the observed pumping.

Two locations along the westbound lanes where fines on the shoulder indicated that pumping had occurred were selected for excavation and examination. A third location along the westbound lanes was selected where no pumping or pavement distress was evident.

The first excavation area was approximately at Station 135 + 10, where stains along the shoulder indicated that pumping had occurred. When the trench was excavated, water approximately 1 ft deep was found between the prefabricated pavement base drain and the pavement subgrade. Once a section of prefabricated pavement base drain had been cut free and removed from the trench, its core was found clogged with fine-grained soil throughout the entire height of the drain.

After the prefabricated pavement base drain had been removed, soil samples were taken from both the pavement and shoulder sides of the prefabricated pavement base drain for gradation analysis. Approximately 10 ft of prefabricated pavement base drain was removed and replaced at each of the three excavation locations, even though the adjacent prefabricated pavement base drain was mostly to entirely filled with fines. At all three excavation locations, soil samples were taken adjacent to the prefabricated pavement base drain and the shoulder was rebuilt.

The second excavation location was approximately at Station 134 + 50 westbound. Fines on the shoulder indicated the occurrence of pumping at this location. Once excavated, the prefabricated pavement base drain was also found to be totally filled with fines.

The third excavation location was approximately at Station 107 + 00 westbound. No pumping was noted at this location during the June 1988 research project inspection to select locations for excavation or during July 1988 when the prefabricated pavement base drain was excavated in this area of the research project site. Once excavated, the prefabricated pavement base drain was also found to be mostly clogged. The results of the gradation analyses of the soil samples taken adjacent to the prefabricated pavement base drain at this and the other two excavation locations are shown in Table 1.

TABLE 1 GRADATION ANALYSES OF MATERIAL ADJACENT TO PREFABRICATED PAVEMENT BASE DRAIN

Sieve Size	Percent Passing by Wt
2 in.	100
1–½ in.	100
¾ in.	78–98
⅜ in.	60–77
No. 4	48–61
No. 10	38–49
No. 40	30–40
No. 100	22–32
No. 200	16–24
0.02 mm	11–17
0.002 mm	4–9

The core of the prefabricated pavement base drain at the third excavation location was filled with fine-grained soil approximately 14 in. deep in the roughly 18-in.-high drain. Because no pumping had been evident before excavation, finding the prefabricated pavement base drain clogged at this location on the project raised the question of how much more of the prefabricated pavement base drain was clogged, even in areas where no pumping had yet occurred.

A gradation analysis was done by PennDOT's Materials and Testing Division on nine soil samples taken from the material found clogging the cores of the prefabricated pavement base drain sections excavated. Three samples were taken from the prefabricated pavement base drain excavated at each of three locations. The results of these gradation analyses are shown in Table 2. Six of the samples, which were removed from the prefabricated pavement base drain excavated near Stations 107 + 00 and 134 + 50, were near the fine end of the gradation limits shown in Table 2, with at least 96 percent passing the No. 200 sieve. The three samples taken from material clogging the prefabricated pavement base drain excavated near Station 135 + 10 were near the coarser end of the gradation limits shown in Table 2, with only a minimum of 35 percent passing the No. 200 sieve.

Figure 1 shows two views of the excavated prefabricated pavement base drain without part of the geotextile that wraps the geocomposite core. These photographs illustrate the extent of clogging found in the prefabricated pavement base drain.

The apparent outlet for the first two excavation sites was found approximately at Station 140 + 50 and located at the second inlet down from where the first two clogged sections of prefabricated pavement base drain had been removed. After excavation it was found that the outlet cap of the prefabricated pavement base drain at this location was tilted upward and

TABLE 2 GRADATION ANALYSES OF SOIL FOUND CLOGGING PREFABRICATED PAVEMENT BASE DRAIN

Sieve Size	Percent Passing by Wt
No. 4	100
No. 10	99–100
No. 40	96–100
No. 100	73–100
No. 200	35–100
0.02 mm	13–73
0.002 mm	5–28

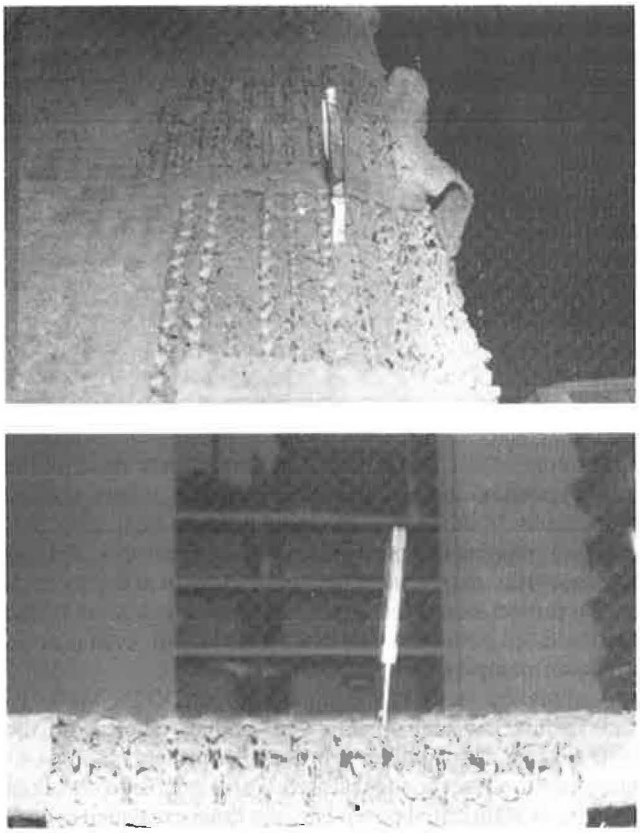

FIGURE 1 Clogged prefabricated pavement base drain (two views).

the cap adapter was partially crushed. This crushing may have been caused by tamping equipment used during trench backfill compaction. The corrugated polyethylene outlet pipe was disconnected from the cap adapter.

The relative elevations of the outlet pipe invert at the outlet cap and outlet end were checked with a lock level and found to be approximately equal. This indicates a flat slope of the outlet pipe, which would not adequately transmit the water away from the pavement. Obviously there were construction-related problems with this particular outlet that could have impeded the flow of water from the pipe.

At this inlet, the prefabricated pavement base drain was clogged within about 1 in. of its top and appeared to run continuously past the inlet. The prefabricated pavement base drain excavated in this area during July 1988 was only clogged approximately 14 in. deep in the core. This possibly indicates that the prefabricated pavement base drain filled with approximately 4 in. of fine-grained soil in that 9-month period. The trench was not excavated immediately adjacent to where the section of prefabricated pavement base drain was removed during July 1988, so it is not possible to determine definitively whether this additional clogging occurred between July 1988 and March 1989.

If the prefabricated pavement base drain became totally filled in this area during this 9-month period, it could explain why fines were found pumped onto the shoulder in March 1989 when no signs of pumping had been found in June 1988. Alternatively, if the prefabricated pavement base drain core was not totally filled, additional fines could still possibly be jetted into the core of the prefabricated pavement base drain. Once the core was filled, additional fines could no longer be jetted into the core and the pore-water pressure buildup might then pump eroded fines onto the roadway shoulder.

The crew then excavated at the inlet near Station 110+00 and found the outlet for the section of prefabricated pavement base drain excavated in 1988. Other than a small amount of soil found near the coupling to the fitting at the end of the prefabricated pavement base drain, the outlet was clear and functional.

The prefabricated pavement base drain itself did not appear clogged near this outlet. This would seem to indicate that an improperly constructed outlet was not the cause of clogging in this area, because water restricted by a nonfunctioning outlet would first back up in the prefabricated pavement base drain near the outlet. If water standing in the prefabricated pavement base drain because of a nonfunctioning outlet caused the core to clog, the core clogging logically would have occurred first near the nonfunctioning outlet.

The maintenance crew excavated the standard pavement base drain trench approximately at Station 103+00 according to site station puddles along the eastbound lanes. Pumping had previously been observed in this area. Two pieces of the Class 1 geotextile wrapping the trench were taken, and the grab tensile strength and percent elongation were determined.

The geotextile test results exceeded PennDOT's specification limits of 90 lb grab tensile strength and 20 percent elongation. No laboratory evaluation was done to determine the amount of clogging in these samples of geotextile, but clogging could have been a problem that contributed to the pumping problem in the area where the geotextile had been removed.

A sample bag of aggregate was taken from the pavement base drain trench for gradation analysis. The sample did not visually appear clogged with an excessive amount of fines. When tested, the AASHTO No. 8 stone removed from the trench was within acceptable gradation limits set forth in PennDOT's specifications (Table 3). Pumped fines had previously been noted on the shoulder in the vicinity of the excavation along the eastbound lanes; however, no pumped fines were clearly evident just before excavation.

As shown in Table 3, the gradation of the AASHTO No. 8 stone removed was not close to the fine end of the gradation limits. This corroborates the subjective judgment that an ex-

TABLE 3 GRADATION LIMITS AND ANALYSIS OF AASHTO NO. 8 COARSE AGGREGATE

	Percent Passing by Weight	
Sieve Size	PennDOT Specified Gradation of No. 8 Coarse Aggregate	Gradation of No. 8 Coarse Aggregate Removed from Project
¾ in.	100	100
½ in.	100	99
⅜ in.	85–100	94
No. 4	10–30	19
No. 8	0–10	3
No. 16	0–5	2
No. 200	2 max.	1

cessive amount of fines had not infiltrated and been retained in the standard pavement base drain system.

OBSERVATIONS

On this project, the prefabricated pavement base drain cost $1.80 per L.F. less than PennDOT's standard pavement base drain system. This initial cost savings is an incentive to use prefabricated pavement base drains instead of the standard perforated plastic pipe and geotextile-wrapped aggregate trench drainage system. Nevertheless, if prefabricated pavement base drains are not as effective as PennDOT's standard pavement base drain, damage caused to the roadway by standing water could cause damage most costly than the $1.80 per L.F. saved by using the prefabricated system.

A report by the California Department of Transportation indicated:

> For rigid pavement, the work of Darter, et al. the results of the California edge drain study and the performance of the retrofit edge drain system on the Valencia-Tarrogona Toll Road, suggest a minimum 50% extension of service life of PCC pavements with an efficient, functioning edge drain system. (*2*)

The California study further indicated that for a roadway consisting of a 0.85-ft-thick PCC pavement over a 0.50-ft-thick asphalt-treated permeable base and a 0.70-ft-thick aggregate subbase and edge drains with outlets there is an achievement of "a 35% annual savings in rigid pavement costs over the service life of the pavement due to its drainage features" (*2*).

The initial costs of prefabricated pavement base drain and PennDOT's standard pavement base drain system are substantially different, but it should be kept in mind that the prefabricated pavement base drain system and PennDOT's standard pavement base drain system are two substantially different drainage systems. Both use a geotextile fabric to filter out fines, but they use different designs to collect and transmit water. The aggregate used in the standard pavement base drain trench also may have varying levels of effectiveness as a filter medium depending on the characteristics of the material being filtered. AASHTO No. 8 stone will not be an effective filter for some Pennsylvania soil types.

There is reason to assume that these different systems will also provide some different advantages and disadvantages, a better understanding of which can be obtained by examining some of the characteristics of the materials used in the drainage systems and how these characteristics may affect performance.

The gradation limits of the AASHTO No. 8 stone used in PennDOT's standard pavement base drain are presented in Table 3, as well as the gradation band for the subgrade materials excavated adjacent to the prefabricated pavement base drain.

The geotextiles wrapping the AASHTO No. 8 stone in PennDOT's standard pavement base drain system and in all prefabricated base drain systems are referred to by PennDOT as Class 1 geotextile. PennDOT specifications require Class 1 geotextiles to have an apparent opening size (AOS) ≥ No. 40 sieve or in other words to have an AOS ≤425 mm.

The filter fabric wrapping the prefabricated pavement base drain core has a typical minimum average AOS equal to a No. 70 sieve, which corresponds to a sieve opening of 0.212 mm.

An FHWA publication recommends geotextile design and selection criteria for soil retention or piping resistance (*3*). For projects on soils with <50 percent of material passing the No. 200 sieve; dynamic, pulsating, and cyclic flow; and pumping conditions in which individual soil particles are eroded by dynamic flow and jetted into the geotextile, the FHWA contracting officer's technical representative for their *Geotextile Engineering Manual* indicated that the following criterion is appropriate (*3*, p. 3–29; Jerry DiMaggio, unpublished data): 095 ≤ D15.

The D15 value represents the diameter of soil particles at 15 percent fines by weight on the material gradation curve. DiMaggio also emphasized that laboratory test results obtained by modeling specific field conditions should provide more correct design and selection criteria than the 095 ≤ D15 criterion.

The FHWA's *Geotextile Engineering Manual* provides different criteria for steady-state flow conditions than those presented above, but the movement of rigid pavement slabs under traffic loadings would most likely cause dynamic flow conditions.

The material sampled from the trench backfill on the shoulder side of the prefabricated pavement base drain is probably similar to the special subgrade sampled from under the pavement along the prefabricated pavement base drain, because the trench was backfilled with material that had been excavated to allow installation of the prefabricated pavement base drain.

As shown in the following calculations, neither the core of PennDOT's Class 1 geotextile nor that of the fabric-wrapped prefabricated pavement base drain meets FHWA's soil retention design criteria for dynamic flow conditions when required to filter the finest side of the gradation band of material, which is similar to the special subgrade sampled adjacent to the prefabricated pavement base drain on this project.

As shown in the following calculations, AASHTO No. 8 stone meets these criteria from gradation curves for a filter immediately adjacent to the prefabricated pavement base drain:

D5,#8 = 1.2 mm to 3.8 mm,
D10,#8 = 2.3 mm to 4.8 mm,
D15,#8 = 3.2 mm to 5.3 mm,
D50,#8 = 5.9 mm to 7.3 mm,
D60,#8 = 6.5 mm to 7.9 mm,
D85,#8 = 8.2 mm to 9.6 mm,
D15,ss = 0.012 mm to 0.039 mm,
D50,ss = 2.2 mm to 5.5 mm,
D85,ss = 13 mm to 24 mm.

Prefabricated pavement base drain:
Max. D15, ss = 0.039 mm,
Min. D15, ss = 0.012 mm,
095 ≤ D15, ss to meet criteria,
0.212 mm is not ≤ 0.012 mm.
Class 1 geotextile:
Max. D15, ss = 0.039 mm,
Min. D15, ss = 0.012 mm,

095 ≤ D15, ss to meet criteria,
0.212 mm is not ≤ 0.012 mm.

Both geotextiles meet the FHWA *Geotextile Engineering Manual* criteria for steady-state flow that the AOS be less than or equal to the D85 (15 to 26 mm) value of the soil to be filtered, but, as discussed earlier, the traffic loadings on rigid slabs would most likely cause dynamic flow conditions. As shown by the pumping, there was quite a bit of slab movement on this project, which would have built pore pressures and have jetted water and fines from under the pavement toward its edge.

FHWA described the following criteria for design of protective granular filters (*4*, p. 98):

D15, No. 8 ≤ 5 (D85,ss),
D15, No. 8 ≥ 5 (D15,ss),
D50, No. 8 ≤ 25 (D50,ss),
D5, No. 8 ≥ 0.074 mm,
Cu, No. 8 = D60, No. 8/D10,#8 ≤ 20.

Comparing the AASHTO No. 8 stone with the FHWA criteria results in the following:

D15, No. 8 ≤ 5 (D85, ss),
4.9 mm ≤ 5 (13 mm),
4.9 mm ≤ 65 mm meets criteria.

D15, No. 8 ≥ 5 (D15, ss),
3.1 mm ≥ 5 (0.039 mm),
3.1 mm ≥ 0.20 mm meets criteria.

D50, No. 8 ≤ 25 (D50, ss),
7.3 mm ≤ 25 (2.3 mm),
7.3 mm ≤ 57.5 mm meets criteria.

D5, No. 8 ≥ 0.074 mm,
1.2 mm ≥ 0.074 mm meets criteria.

Cu, No. 8 = D60, No. 8/D10, No. 8 ≤ 20,
7.9 mm/2.3 mm = 3.2 ≤ 20 meets criteria.

Therefore, by these criteria, the AASHTO No. 8 stone used in PennDOT's standard pavement base drain system is an acceptable filter medium for the gradation of special subgrade material excavated from this research project site. The standard pavement base drain system effectively has a two-filter system. In this particular instance, the Class 1 geotextile wrap around the standard base drain system may not have been necessary.

The facts that the core of the prefabricated pavement base drain was found clogged in the three sections excavated and that the geotextile wrapping the prefabricated pavement base drain was shown not to meet the FHWA *Geotextile Engineering Manual* criteria for soil retention or piping resistance under dynamic flow conditions raise questions as to whether the core clogging caused by the jetting of fines through the geotextile could occur at other locations where extreme pumping conditions exist.

It is not a problem for some fines to move through the prefabricated pavement base drain fabric and into the core if these fines can be flushed out the drainage outlet. However, if there are problems that restrict the flow through the geocomposite or there simply is not enough flow velocity to carry away these fines piped through the fabric, the core will eventually clog.

It is difficult to estimate to what extent the core of the prefabricated pavement base drain near Stations 134 + 50 and 135 + 10 would have been clogged if the outlet serving those areas had been totally functional. A crushed, clogged, or otherwise nonfunctioning outlet could restrict the flow of water through the geocomposite, preventing fines from being carried through the geocomposite and discharged from the outlet. However, the prefabricated pavement base drain core itself was not clogged near the partially crushed outlet for these first two prefabricated pavement base drain sections excavated in July 1988, indicating that the outlet was probably not the only factor influencing the clogging. If restricted flow caused by a nonfunctioning outlet had been the sole problem, it seems probable that there would have been core clogging in the entire prefabricated pavement base drain system upstream from the restriction.

It is also doubtful whether nonfunctioning outlets were the only reason for the clogging of the core, because extensive clogging was found in the prefabricated pavement base drain section excavated near Station 107 + 00. The outlet serving this section appeared functional, and the prefabricated pavement base drain near this outlet did not appear clogged. It appears that there must have been restrictions in the prefabricated pavement base drain core or the invert slope of 3 percent was too low to provide sufficient flow velocities for the system to cleanse itself.

Industry obviously realizes the dynamic flow conditions to which geocomposite edge drains are subjected. In Monsanto's report to PennDOT to describe the performance of prefabricated pavement base drains under dynamic loadings (*5*) a paper entitled "A Dynamic Test to Predict the Field Behavior of Filter Fabrics Used in Pavement Subdrains" (*6*) is provided as an appendix. In this paper, Janssen states that it was "very likely" that fines were pumped through the fabric.

Janssen states:

> It is felt that a graded filter structure was being built up adjacent to the fabric as fines migrated down through the sample. At 300,000 loads this structure collapsed, causing a rapid decrease in permeability. From here the permeability again gradually decreases, possibly caused by the accumulation of fines adjacent to the fabric.
>
> At about 675,000 loads the permeability suddenly increased. Prior to that, at about 650,000 loads, the water again appeared cloudy. It is very likely that the high hydraulic gradient right above the filter along with the stretching of the fabric pores caused piping of the fines through the fabric. This gives the appearance of a "self-cleaning" action. The wide fluctuations in permeability between 675,000 and 700,000 loads may possibly have been caused by soil structure collapse followed by more soil piping. (*6*, p. 11)

The above excerpt from Janssen's paper refers to a graded soil filter. The FHWA *Geotextile Engineering Manual* describes the formation of a soil filter to act in conjunction with a geotextile as follows:

> As fine soil moves through the fabric, larger particles may combine to bridge the apertures of the fabric. Immediately

> behind this bridging zone is another zone consisting of soil particles whose permeability decreases with distance from the geotextile. . . . In the past, this zone has been termed "filter cake" or "soil filter." The zone behind the soil filter is actually the undisturbed existing soil. Once the soil filter zone has been established, no further soil is washed through the system and the system is considered to be in equilibrium. The soil filter zone is, in effect, a reverse granular filter constructed solely from the in situ soil particles. (*7*)

The key phrase in the above discussion is "considered to be in equilibrium." Apparently, in Janssen's testing, the dynamic forces were enough to destroy this equilibrium and cause a breakdown of the soil filter as additional fines were passed through the fabric.

CONCLUSIONS

Although geocomposites show great promise in drainage applications and have been used successfully on many pavements, the problems reported on this project raise concerns that must be addressed. On this project, prefabricated pavement base drains do not appear to perform as well as PennDOT's standard pavement base drain. Although the flow data collected appear to be inadequate to be considered conclusive, the flows measured from the prefabricated pavement base drain were consistently less than the flows measured from PennDOT's standard pavement base drain. It appears that slightly more trench subsidence and pumping took place along the prefabricated pavement base drain than along the standard pavement base drain system.

Core clogging on I-70 was believed to be caused by the AOS of the geotextile, which was too open to retain the high fines percentage under the dynamic loading conditions. Once the fines had entered the core, they may not have been flushed out because of the small amount of water entering the core or blockage of the core downstream, which did not allow for adequate flow velocities.

It should be kept in mind that the crushed outlet pipe, the finer-than-normal subbase material, and the harsh pavement pumping conditions influenced some of the less-than-acceptable performance of prefabricated pavement base drains on this project.

From an economic viewpoint, the initial bid cost of prefabricated pavement base drains is less than that of PennDOT's standard pavement base drain system. However, the cost of roadway damage caused by water left under the roadways could far exceed initial cost savings obtained by using the prefabricated pavement base drain.

When the costs of either type of pavement base drain evaluated in this paper are considered relative to the total cost of a roadway and the damage that water in pavement structures can lead to, it seems that if either type of drainage system does not adequately drain the roadway or does not maintain its effectiveness over the life of a roadway, using that type of pavement base drain system will not be a truly cost-effective alternative. Therefore, from an economic standpoint, cost over performance life rather than initial cost should be stressed the most in evaluating the type of pavement base drain system that should be installed on PennDOT projects. Maintenance and periodic replacement costs for nonfunctioning drains must be factored into the life-cycle cost analysis.

The tendency of the prefabricated drain to clog where pumping dynamic conditions exist along rigid pavements should be studied further. In particular, the fabric opening size characteristics need to be compared with the percentage of fines being retained in the soil.

IMPLEMENTATION

On the basis of the findings and recommendations of this evaluation and on PennDOT Research Project 88-15 performed at Drexel University, generic specifications for prefabricated drains were developed and the outlet pipe specifications were changed (*8*):

1. The core strength load deflection requirement was changed from a maximum 20 percent strain at 20 psi to a crush strength of 40 psi minimum per the Geosynthetic Research Institute at Drexel University's Test GRI-GC4.
2. The core flow rate must be at least 15 gal/min-ft, per ASTM-D4716.
3. The core must permit unobstructed flow through 50 percent of the fabric area on the pavement side of the pavement base drain, and 20 percent of the fabric area on the shoulder side face was added.
4. The AOS specification of the geotextile fabric was changed from a U.S. Sieve No. 70 per CW-02215 to a U.S. standard Sieve No. 70 minimum per ASTM-D4751.
5. The permeability required of the geotextile was changed from 0.2 cm/sec per PTM No. 314 to 0.001 cm/sec per ASTM-D4491.
6. The minimum width of the trench was specified to be the thickness of the pavement base drain plus 1 in.
7. The prefabricated pavement base drain is to be placed on the shoulder side of the trench instead of on the pavement side.
8. Fine aggregate backfill is to be placed on the pacement side of the trench instead of excavated material being placed on the shoulder side of the trench.
9. Outlets are to be solid pipe with a minimum stiffness of 45 psi at 5 percent deflection.
10. Outlets are to be installed within 24 hr after the beginning of trenching for installation of a given section of pavement base drain.

ACKNOWLEDGMENTS

Sincere appreciation is expressed to PennDOT Engineering District 12-0 personnel for their considerable efforts during this evaluation. Washington County maintenance personnel were particularly helpful. Appreciation is also expressed to PennDOT's Materials and Testing Division for their soil analysis testing.

This work was performed with financial sponsorship from FHWA and with the approval and assistance of PennDOT's Office of Research and Special Studies, Bureau of Bridge and Roadway Technology, and Materials and Testing Division.

REFERENCES

1. K. Highlands and R. Turgeon. *MDM Highway Drainage Mat.* Construction Report, Research Project No. 83-30. Pennsylvania Department of Transportation, Harrisburg, Sept. 1985.
2. R. A. Forsyth et al. *The Economic Impact of Pavement Subsurface Drainage.* California Department of Transportation, Sacramento, Jan. 1987.
3. B. R. Christopher and R. D. Holtz. *Geotextile Engineering Manual.* FHWA, U.S. Department of Transportation, March 1984.
4. L. K. Moulton. *Highway Subdrainage Design.* Report FHWA-TS-80-224. FHWA, U.S. Department of Transportation, Aug. 1980.
5. Monsanto Engineered Products Division and B. J. Dempsey. *The Design and Testing of Monsanto Drainage Mat (MDM).* Monsanto Company, St. Louis, Mo., Nov. 1983.
6. D. J. Janssen. *A Dynamic Test to Predict the Field Behavior of Filter Fabrics Used in Pavement Subdrains.* Department of Civil Engineering, University of Illinois, Urbana, Aug. 1982.
7. C. R. Lawson. Filter Criteria for Geotextiles: Relevance and Use. *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 108, No. GT10, Oct. 1982. Cited in *Geotextile Engineering Manual*, FHWA, March 1984.
8. R. M. Koerner and B. Hwu. *Geocomposite Drainage Systems (Highway Edge Drains and Retaining Wall Sheet Drains).* Final Report, Research Project 88-15. Pennsylvania Department of Transportation, Harrisburg, Dec. 1989.