Core Flow-Capacity Requirements of Geocomposite Fin-Drain Materials Used in Pavement Subdrainage

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A study was conducted to determine the core flow-capacity requirements of geocomposite fin-drain materials used in pavement subdrainage. The study consists of a laboratory testing program, field subdrainage outflow studies, and analysis of all data to define the fin-drain core flow-capacity requirements. Six different fin-drain materials were tested in a 24-ft-long laboratory channel to establish their core flow properties. The tests were conducted at three different entrance heads (6.3 in., 12.3 in., and 18.4 in.) and at slopes of 0, 1, 2, 3, and 4 percent. Field subdrainage outflow data were obtained from two test sites in Illinois. These data are presented in terms of volume of outflow as a function of time. The data were collected by use of tipping-bucket flow meters. A comparison was made between the observed core flow capacity of the fin-drain materials in the laboratory and the flow volume observed from field subdrainage systems. Based on this comparison, it was indicated that geocomposite fin-drain systems will be required to provide flow zone capacities in excess of 150 gal/hr at 0 percent pavement gradient and in excess of 200 gal/hr at gradients of 1 percent or greater to compare with a standard pipe and sand envelope system. When compared with a more permeable aggregate envelope system or a high-performance fin-drain system, flow zone capacities in excess of 200 gal/hr to 300 gal/hr may be desirable depending upon the pavement gradients and the number and size of joint and crack openings. Based on faulting measurements, it is indicated that a fin-drain subdrainage system can improve pavement performance to a level equivalent to or better than that for some standard systems.

One of the major changes in the new *AASHTO Guide for Design of Pavement Structures* was the provision for guidance in the design of subsurface drainage systems and for modifying the design equations to take advantage of improvements in pavement performance resulting from good drainage practices (*1*). Although it is left up to the design engineer to identify what level or quality of drainage is achieved under specific drainage conditions, a set of general definitions corresponding to different drainage levels for a pavement structure is presented in Section II of the AASHTO Guide (*1*). These drainage levels are shown in Table 1.

While some states are just beginning to initiate drainage design standards, numerous others have had design standards for a considerable period of time and have constructed many miles of pavement subdrainage. Follow-up studies in Illinois, California, and several other states have indicated that effective structural pavement drainage decreases pavement distress and increases pavement performance life (*2–4*). Generally these pavement subdrainage systems have consisted of 4-in. to 6-in. perforated pipe placed in a trench along the edge of the pavement system which is backfilled with sand or coarse aggregate envelope material. This system may or may not include the use of a geotextile. Beginning in 1983, the construction of structural pavement subdrainage using geocomposite fin-drain materials came into widespread use. Since that time many states have adopted geocomposite fin drains as an alternate to the standard circular pipe and sand or coarse aggregate envelope systems. In this paper a geocomposite fin drain is defined as a rectangular polymeric core material that is wrapped with a geotextile and that has considerable in-plane water flow capacity.

With the adoption of geocomposite fin-drain materials for pavement subsurface drainage, the question now surfacing in the construction standards is related to the level of performance needed by these materials. In the past the benchmark for drainage has been the standard circular pipe and granular envelope system. Any new drainage concept was required to provide drainage capacity and field performance equivalent to or better than the existing standard. Furthermore, it was indicated that the new concept would have to be cost competitive.

Based on the past 4 yr of pavement subdrainage construction and evaluation it appears that a geocomposite fin-drainage system can be constructed that will provide drainage capacity and field performance that are equivalent to or exceed those of the standard circular pipe at a comparative cost. With the success of the geocomposite fin system for pavement subdrainage, department of transportation design offices are now being approached with a broad range of geocomposite fin

TABLE 1 QUALITY OF DRAINAGE FOR PAVEMENT STRUCTURES (*1*)

Quality of Drainage	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very poor	Will not drain

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products that are purported to meet the flow capacity, strength, and durability properties necessary for pavement edge drainage. The major problem is that there are substantial differences in the flow capacities, strengths, and performance levels of many of these products.

The general objective of this paper is to determine the core flow capacity requirements for pavement subdrainage using geocomposite fin-drain materials. The specific objectives are as follows:

- Evaluate the core flow capacities of long sections of selected geocomposite fin-drain materials in the laboratory based on channel slope and entrance head;
- Establish the volume of subdrainage outflow for typical pavement systems in the field; and
- Define, based on quantitative laboratory and field data, the core flow capacity requirements for geocomposite fin-drain materials used in pavement edge drainage systems.

FIGURE 2 View of flow channel and a test section of fin-drain material from downstream end.

LABORATORY TESTING PROGRAM AND DATA

Laboratory Testing Equipment

The inlet end of the channel used for testing the core flow capacities of selected fin-drain materials is shown in Figure 1. The channel view from the downstream end is shown in Figure 2. The main equipment components used in the testing program consist of the flow channel which contains the fin-drain material and a weir box for measuring the volume of water flow. A schematic diagram of the laboratory testing equipment is shown in Figure 3.

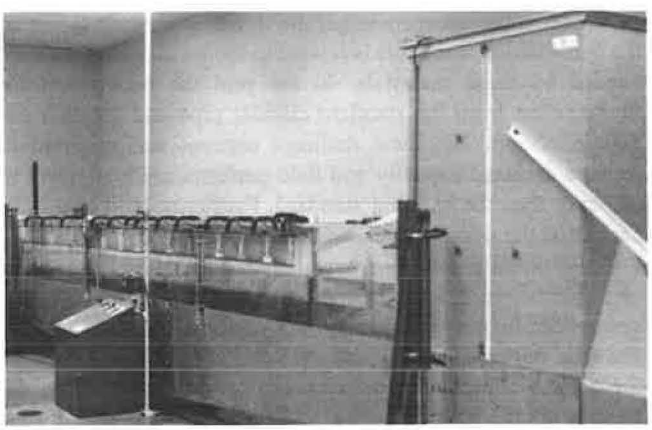

FIGURE 1 View of flow channel and a test section of fin-drain material from inlet end.

The testing equipment is located in the Hydrosystems Instruction Laboratory at the University of Illinois. The Plexiglas™ channel has a usable length of 24 ft, width of 1.5 ft, and depth of 2 ft. Channel slope can be varied from –5 to +15 percent through the use of hydraulically operated cylinders.

Flow to the channel is supplied from a constant head tank, which has a crest elevation of approximately 53 ft above the laboratory floor. The flow passes through a series of supply lines into an 8-in.-diameter pipe which empties into the 5-ft-high by 4-ft-long by 1.5-ft-wide head tank of the tilting channel. A series of baffles is located within the head tank as well as at the entrance of the channel to dampen the turbulence of the approach flow. The flow rate is regulated by a butterfly valve system installed in the 8-in. supply line.

Flow leaving the channel passes through an exit chute and into the weir box (Figure 4). The exit chute separates the measured flow in the fin-drain material from the bypass flow. The weir box is perpendicular to the end of the channel and empties into an underground sump. Water within the sump is pumped by a vertical turbine pump back into the main head tank where it reenters the water supply system.

The flow rate was measured through the use of a 20 degree sharp-crested V-notch weir plate attached to the 6-ft-long weir box located beneath the exit chute at the downstream end of the channel (Figure 4). The head above the crest of the weir was measured with a point gauge situated in a stilling well attached to the side of the weir box. The weir box was designed to accurately measure flows to within 0.5 gal/hr.

Laboratory Testing Procedure

The laboratory testing procedure was developed to evaluate the core flow capacity of nominal 12-in. geocomposite fin-drain sections 20 ft long. The geocomposite fin-drain material was sandwiched between one side of the Plexiglas flow channel and a plywood plate. The fin drain was firmly placed so that no flow occurred between the fin exterior and the wall restraints. The top of the fin drain was also sealed so that, even under a submerged entrance head, all flow would be confined to the fin-drain core. Water level at the entrance of the fin-drain material was controlled by the pipe inlet valve and by a small spillway (Figure 5), which diverted excess water to the channel flow area behind the braced plywood backing plate. By use of different spillway heights, core flow capacities at entrance head levels of approximately 6 in., 12 in., and 18 in. were evaluated during the testing program. Water that passed over the spillway was diverted away from the weir box at the outlet end by use of the baffles in the exit chute (Figure 4). Flow measurements were conducted at 0, 1, 2, 3, and 4 percent channel slopes.

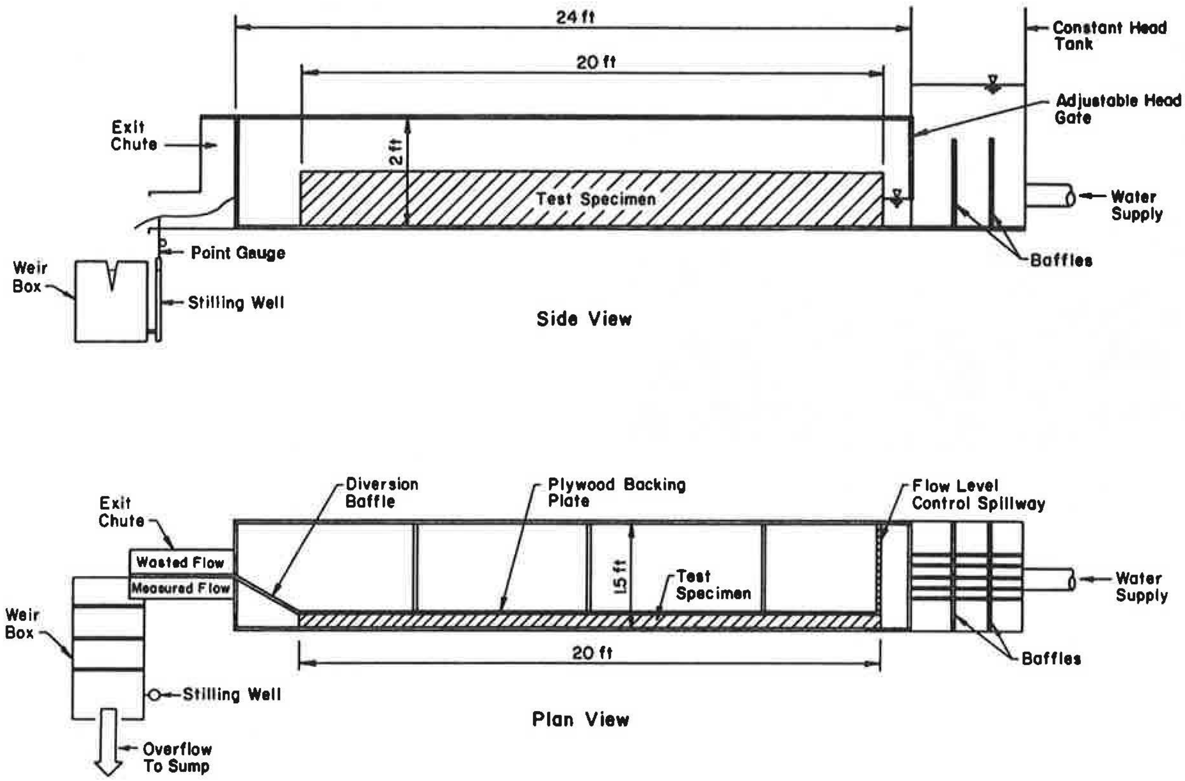

FIGURE 3 Schematic plan and side view of laboratory testing equipment.

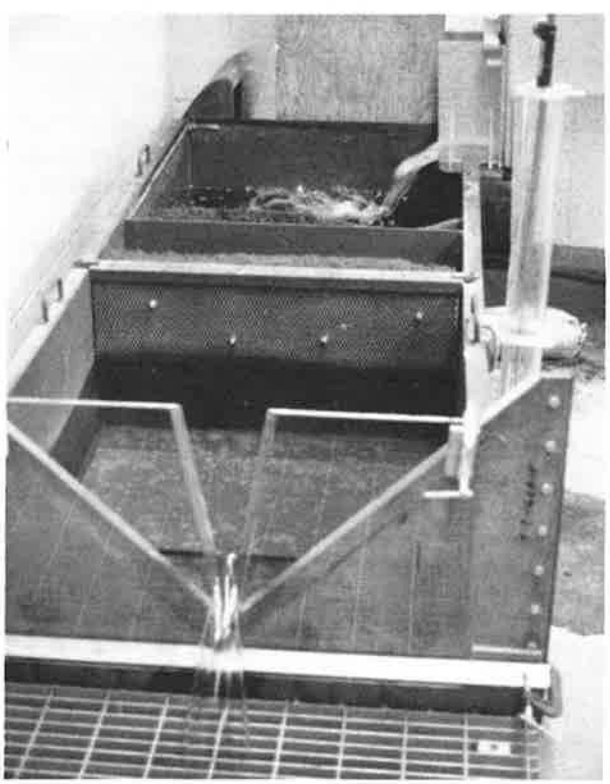

FIGURE 4 Weir box with 20 degree sharp-crested V-notch weir plate.

The quantity of flow measured at the 20 degree sharp-crested V-notch weir was computed by use of the following equations (*5*):

$$Q = 8/15\ C_d \tan \theta/2\ [2g(H)^5]^{1/2} \quad (1)$$

$$H = h + 0.0095 \quad (2)$$

where

Q = flow volume, ft^3/s,
C_d = weir coefficient of 0.593,
θ = V-notch weir angle, degrees,
g = gravity term, 32.2 ft/s^2, and
h = depth of flow in the V-notch weir, ft.

Based on catch sample volume measurements at the weir, Equation 1 was found to provide flow volume predictions that compared favorably with the catch samples throughout the range of flows evaluated in the testing program.

Fin-Drain Materials Tested

A description of the core and fabric wrap of the selected geocomposite fin-drain materials evaluated in this testing program is provided in Table 2. All of the fin-drain materials were

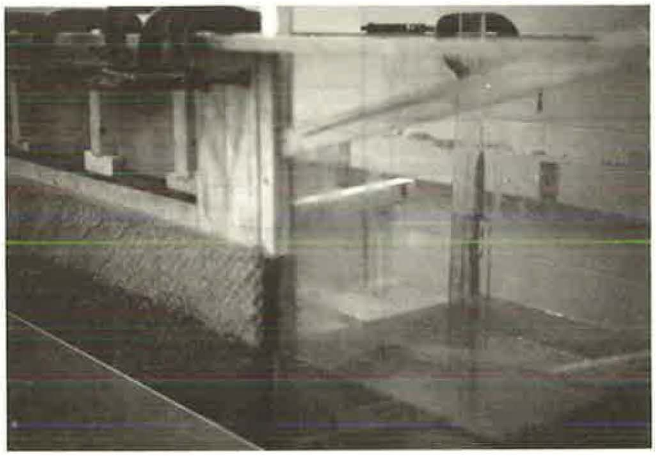

FIGURE 5 Entrance head control in a fin-drain material by using a 6-in. spillway height.

tested as supplied by the manufacturer and all test sections were 20 ft long with a nominal depth of 12 in.

Test Data

The core flow capacities of the geocomposite fin-drain materials as a function of channel slope and entrance head are presented in Table 3. The average entrance heads were 6.3 in., 12.3 in., and 18.4 in. The flow volumes for fin-drain materials A, B, and C represent total two-sided flow since these materials have a centrally located impermeable core membrane. Products D, E, and F use open core systems that do not divide flow.

FIELD SUBDRAINAGE OUTFLOW STUDIES

Typical subdrainage outflow with time relationships, developed from a previous research project, for several precipitation events on I-57 near Champaign, Illinois, during 1978 are shown in Figures 6 through 8 (6).

TABLE 3 LABORATORY FLOW VOLUMES AS A FUNCTION OF CHANNEL SLOPE AND ENTRANCE HEAD FOR 20-FT-LONG SECTIONS OF GEOCOMPOSITE FIN-DRAIN MATERIALS

Fin-Drain Material	Entrance Head (in.)	Flow Volume (gal/hr) for Channel Slope Percentage: 0	1	2	3	4
A[a]	6.2	110	158	189	223	249
B[a]	6.3	387	550	670	782	892
C[a]	6.3	98	133	154	189	215
D	6.3	45	67	79	93	108
E	6.1	270	357	407	495	564
F	6.4	21	30	39	47	55
A[a]	12.2	305	380	435	495	536
B[a]	12.3	1,065	1,281	1,444	1,601	1,787
C[a]	12.5	273	336	380	423	468
D	12.2	147	170	191	220	237
E	12.4	655	794	892	990	1,080
F	12.5	66	92	106	114	133
A[a]	18.2[b]	517	598	660	703	753
B[a]	18.5[b]	1,692	1,875	2,026	2,163	2,284
C[a]	18.5[b]	443	490	541	564	584
D	18.4[b]	218	252	273	295	318
E	18.3[b]	997	1,137	1,235	1,350	1,390
F	18.5[b]	123	141	153	165	178

NOTE: All test sections 12 in. nominal depth; see Table 2 for material description.
[a]Two-sided flow.
[b]Submerged entrance.

Figures 6 and 7 show outflow for a continuously reinforced pavement with unsealed and sealed pavement edge-shoulder joints, respectively. An outflow relationship for a conventional reinforced, jointed concrete pavement with 100-ft joint spacings is shown in Figure 8. Both the jointed and continuously reinforced pavement test sections had longitudinal slopes less than 1 percent. The pavement edge drainage systems used are shown in Figure 9. Flow measurements were conducted at outlets spaced at 500-ft intervals. Outflow was measured at the test site by using a tipping-bucket flow meter (6).

Typical subdrainage outflow with time relationships obtained from I-80 near Morris, Illinois, during 1983 and 1984

TABLE 2 DESCRIPTION OF GEOCOMPOSITE FIN-DRAIN MATERIALS TESTED

Fin-Drain Material	Core Data: Structure	Core Data: Material	Core Data: Thickness (in.)	Fabric Data: Material	Fabric Data: Fabrication	Fabric Data: Core Attachment
A	Cuspated	HDPE[a]	0.78	Polypropylene	Nonwoven	Loose wrapped
B	Cuspated	HDPE	1.57	Polypropylene	Nonwoven	Loose wrapped
C	Cuspated	HDPE	1.00	Polypropylene	Nonwoven	Adhesive bond one side, loose one side
D	Dimpled sheet	HIPS[b]	0.38	Polypropylene	Nonwoven, needle punched	Adhesive bond two sides
E	Columns	LLDPE[c]	1.00	Polypropylene	Nonwoven, needle punched, calendered	Adhesive bond to columns, heat bond backing
F	Net	LDPE[d]	0.25	Polypropylene	Nonwoven	Linear adhesive bond line both sides

[a]HDPE = High-density polyethylene.
[b]HIPS = High-impact polystyrene.
[c]LLDPE = Linear low-density polyethylene.
[d]LDPE = Low-density polyethylene.

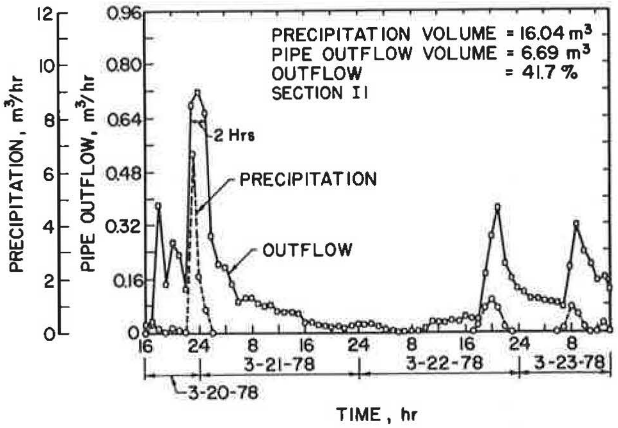

FIGURE 6 Influence of precipitation on subdrainage outflow in a continuously reinforced concrete pavement section without a sealed edge joint (*6*).

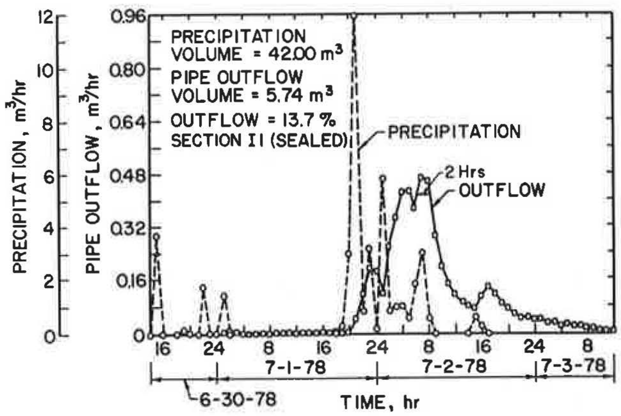

FIGURE 7 Influence of precipitation on subdrainage outflow in a continuously reinforced concrete pavement section with a sealed edge joint (*6*).

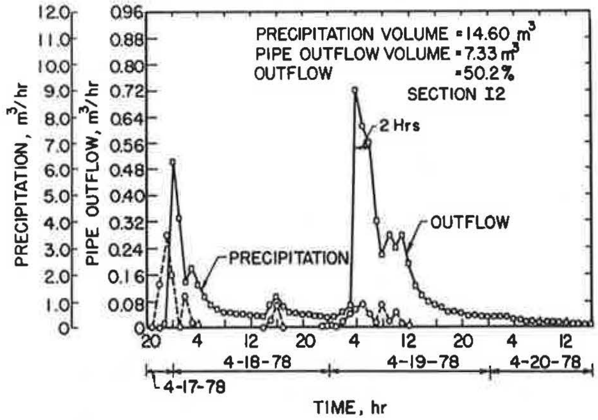

FIGURE 8 Influence of precipitation on subdrainage outflow in a jointed concrete pavement section without a sealed edge joint (*6*).

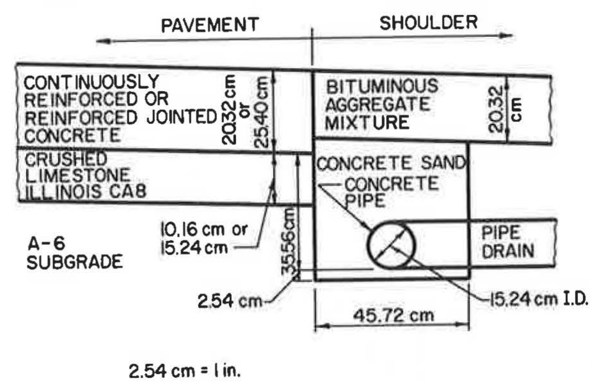

FIGURE 9 Subdrainage systems at test sections on I-57 in Illinois.

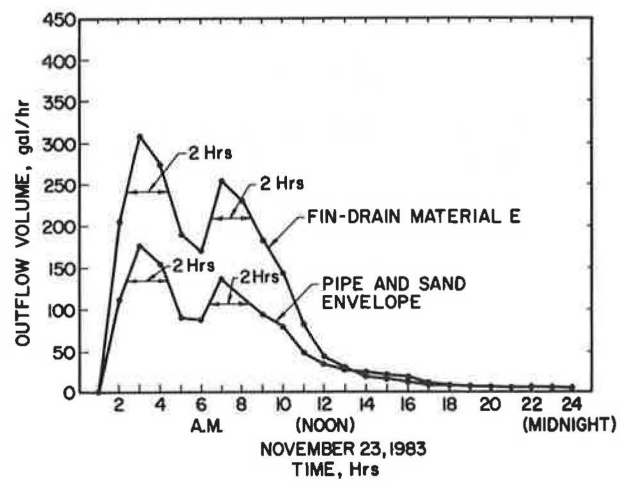

FIGURE 10 Subdrainage outflow volumes from I-80 near Morris, Illinois, for precipitation event on November 23, 1983.

are shown in Figures 10 through 13.. This study was conducted by the Illinois Department of Transportation (IDOT) to compare outflow between a standard 4-in.-diameter polyethylene pipe and sand envelope system and an 18-in.-deep geocomposite fin-drainage system (fin drain E in Table 2). The longitudinal slopes of the two pavement test sections were less than 1 percent. An outlet spacing of 500 ft was used for both drainage test sections. Tipping-bucket flow meters were used to measure the outflow volumes (*6*).

ANALYSIS AND DISCUSSION OF LABORATORY AND FIELD STUDIES

Laboratory Results

As shown in Table 3, there is a broad range of core flow capacities for the various fin-drain materials presently on the market. It is also apparent that core flow capacity is dependent upon the core dimensions, core geometry, entrance head, and channel slope. Graphical relationships between the core flow capacities of the various fin-drain test sections and channel slopes for different entrance heads are shown in Figures 14 through 16. Figure 14 shows the core flow capacities for nominal 12-in.-deep fin-drain sections with a 6.3-in. entrance head (an entrance flow of about 1/2 of the nominal depth of the fin-drain section). It is interesting to note the range of differences between the core flow capacities of the materials tested. Fin drain B with a 1.57-in. core thickness displayed the highest flow capacity with channel slope. As expected, the core capacity of this product increased as the entrance head was increased as shown in Figures 15 and 16. The core flow capacities shown in Figure 15 for the average 12.3-in. entrance

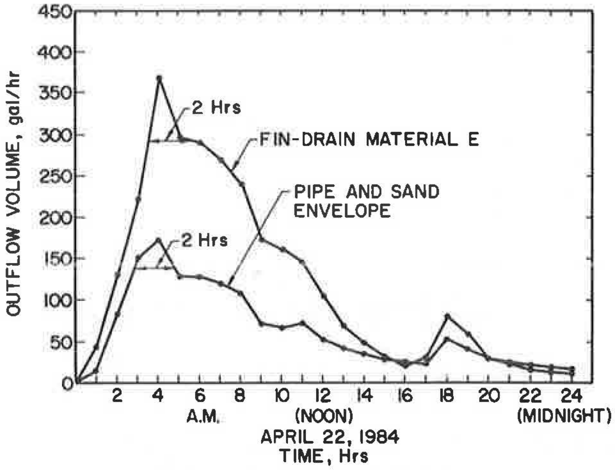

FIGURE 11 Subdrainage outflow volumes from I-80 near Morris, Illinois, for precipitation event on April 22, 1984.

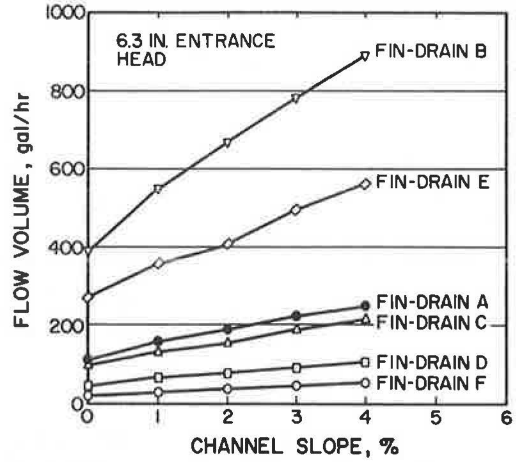

FIGURE 14 Relationships between core flow capacity and channel slope at 6.3-in. average entrance head.

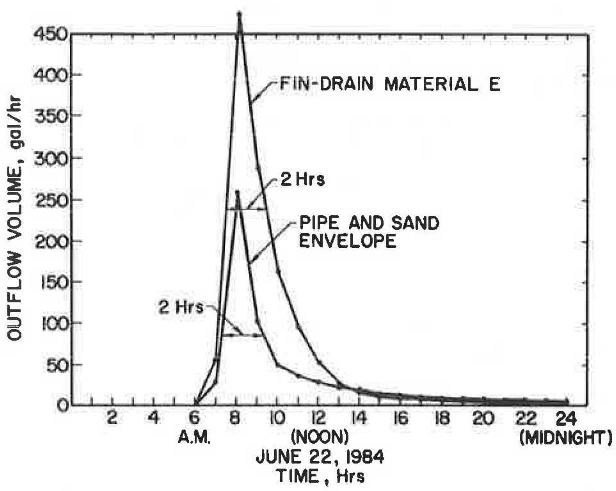

FIGURE 12 Subdrainage outflow volumes from I-80 near Morris, Illinois, for precipitation event on June 22, 1984.

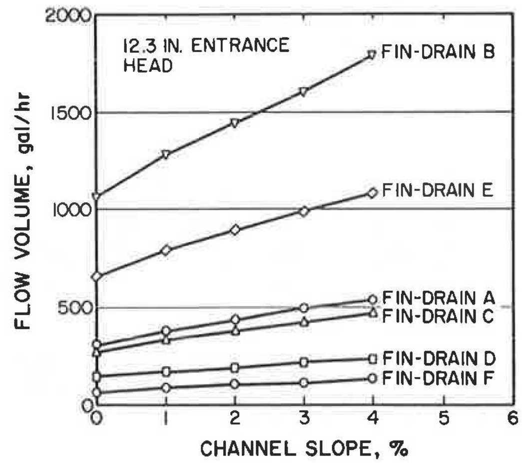

FIGURE 15 Relationships between core flow capacity and channel slope at 12.3-in. average entrance head.

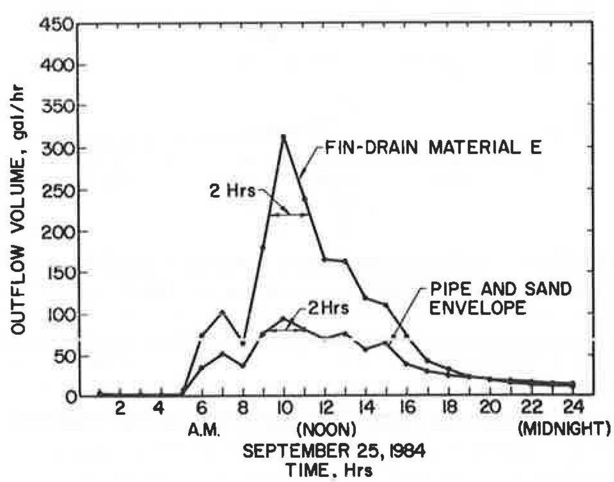

FIGURE 13 Subdrainage outflow volumes for I-80 near Morris, Illinois, for precipitation event on September 25, 1984.

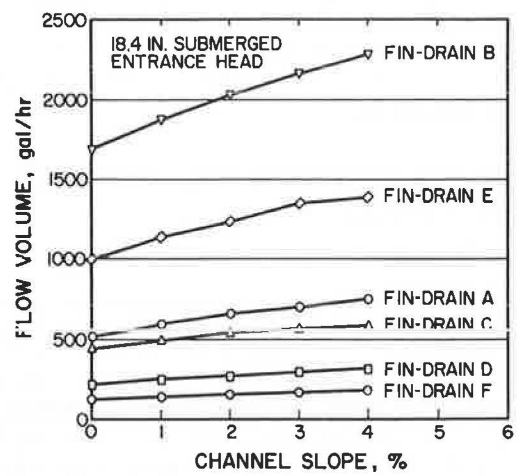

FIGURE 16 Relationship between core flow capacity and channel slope at a submerged 18.4-in. average entrance head.

head provide data for full flow in nominal 12-in.-deep fin-drain sections. The submerged head flow capacities shown in Figure 16 are of general interest to the evaluation of core geometry on flow capacity and would not be the normal situation for pavement edge drainage.

Fin drains C and E have similar dimensions of 1 in. wide by 12 in. deep (Table 2). Figures 14 through 16 show that the core flow capacities of these two products are substantially different throughout the range of channel slopes evaluated. The fin-drain E core capacity ranges from 1.4 to 1.7 times greater than the fin-drain C core capacity regardless of entrance head and channel slope. It is evident that core geometry has a major influence on the flow capacities of these two products which have similar outside dimensions. In fact, in Figures 14 through 16 it is shown that fin drain A with a 0.78-in. core thickness provided greater flow capacity than the 1-in. fin-drain C core, regardless of entrance head or channel slope.

Except for the fin-drain C material, the core flow capacities of the fin-drain materials tested increased relative to the core thickness. Although flow volume is related to core thickness, there is not a proportional relationship between fin drains with different core geometries (Figures 14 through 16).

Relationships Between Laboratory Results and Field Requirements

A sketch of a typical pavement structural subdrainage system using a fin drain is shown in Figure 17. An important consideration when choosing a fin-drain system or pipe envelope system is that adequate trench depth and width are provided to ensure that the water does not back up into the pavement structural layers while being carried to the outlet. Since the fin drain functions as both a collector and a conduit it needs proper dimensions (thickness and width), flow capacity, and outlet spacing to maintain the water level in the fin core at a depth below the pavement structural layers a majority of the time. In Figure 17 this flow should be restricted to that portion of the fin below the subbase-subgrade interface or "freeboard" area. Based on Table 1 the core flow capacity in the "flow zone" below the freeboard area should be such that water will not be retained in the structural pavement section for more than 2 hr for excellent drainage nor more than 1 day for good drainage.

In referring to Figures 6 through 13 it becomes apparent that

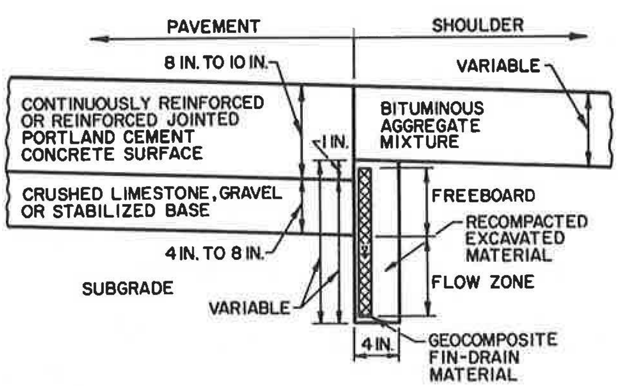

FIGURE 17 Typical geocomposite fin-drain system showing freeboard and flow zone areas.

the Illinois standard subdrain system with a sand envelope can display 2-hr periods with outflow volumes ranging from approximately 70 gal/hr to over 150 gal/hr. The fin-drain system (fin drain E in Table 2) in Figures 10 through 13 shows even higher 2-hr-period outflow volumes which range from approximately 220 gal/hr to almost 300 gal/hr. It is probable that a pipe subdrainage system with a coarse aggregate envelope would provide outflow volumes similar to this fin-drain system.

From the observed outflows for the Illinois standard pipe drain system and for the fin-drain system it would appear that the flow zone capacity of a fin-drain core should be in excess of 150 gal/hr to match a standard pipe and sand envelope system and in excess of 300 gal/hr to match a quality geocomposite, fin-drain system in order to provide excellent drainage performance (drainage of structural pavement section in 2 hr or less).

In the past it has been a common practice to construct the fin-drain system with at least 4 to 6 in. of the drain extending into the subgrade below the subbase-subgrade interface or flow zone area in order to function as a conduit to carry water to the outlet. In referring to Table 3 and Figures 14 through 16 it can be seen that only fin drain B with a flow capacity of 387 gal/hr (0 percent slope) to 892 gal/hr (4 percent slope) and fin drain E with a flow capacity of 270 gal/hr (0 percent slope) to 564 gal/hr (4 percent slope) would qualify as excellent subdrainage systems under the new AASHTO Guide criteria (Table 1) if a 6-in. flow zone is desired. This is not to say that the other fin drains cannot be used, however. The flow capacities of fin drains A and C could be improved by increasing their overall depth dimension to provide a flow zone depth of approximately 12 in. or possibly by decreasing outlet spacing. It is important to note that the centrally located impermeable core used by fin drains A, B, and C may be restrictive, and total core flow capacity may be less than that shown in Table 3. Furthermore, the flow capacities shown in Table 3 were measured for conditions of no fabric sag into the core. Fin-drain materials in which the fabric is loose-wrapped around the entire core or a portion of the core should be used with the understanding that actual field flow capacities may be considerably less because of excess fabric sag into the core. In fact, both laboratory and field observations made during this study indicated that fin-drain materials using a loose-wrapped fabric would have a high probability of diminished core flow capacity because of fabric sag into the core. It is felt that those fin-drain materials with the fabric bonded to the core are less likely to experience detrimental fabric sag into the core during construction operations and during their performance life.

Core flow capacity and flow efficiency are being found important to pavement performance. By quickly removing water from the structural pavement section and not allowing the water which seeps into the pavement edge shoulder joint to flow into the structural base or subbase sections, it is felt that pavement performance can be improved. Both joint faulting and transverse crack faulting on the outside lanes of I-80 near Morris, Illinois, are shown in Figures 18 and 19. The westbound lane is drained by fin drain E described in Table 2. The eastbound lane is drained using the standard Illinois subdrainage system composed of a 4-in. fabric wrapped, perforated, polyethylene pipe with a sand envelope. Three 1,000-ft test sections were measured in each of the two directions. The pavement had been ground smooth in the summer of 1983

when the subdrainage systems were installed. As shown in both Figures 18 and 19 the pavement section with the fin subdrainage system is experiencing considerably less joint and crack faulting than that using the standard system. Average joint faulting after 4 yr (1987) is about 60 percent less and the average crack faulting is about 30 percent less for the fin-drain system as compared to the standard. Traffic data from I-80 near Morris, Illinois, showed that the traffic volume ranged from about 1.3 million 18 thousand single-axle loads (SALs) in 1983 to about 1.7 million 18 thousand SALs in 1987 in the outer lane for each traffic direction. Based on the fact that both westbound and eastbound traffic on I-80 are similar in volume and weight distribution it would appear from Figures 18 and 19 that improved drainage capacity and efficiency provided substantial decreases in joint and transverse crack faulting during the 4 years of pavement service after the surface was ground smooth.

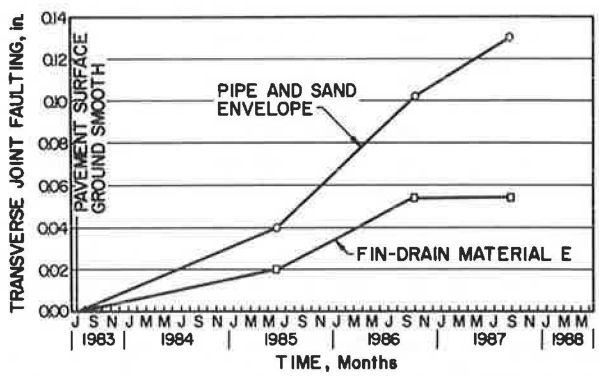

FIGURE 18 Influence of subdrainage type on transverse joint faulting on I-80 near Morris, Illinois.

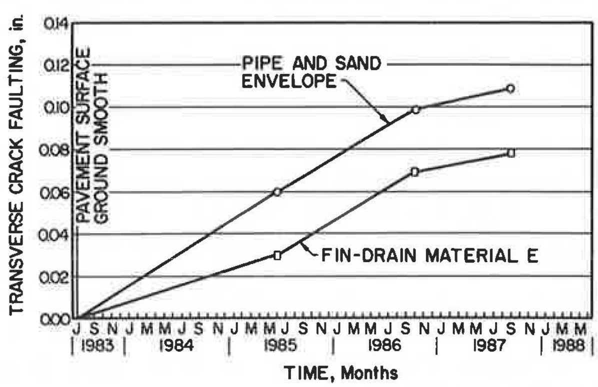

FIGURE 19 Influence of subdrainage type on transverse crack faulting on I-80 near Morris, Illinois.

CONCLUSIONS

Based on field and laboratory evaluations it is felt that any new drainage materials or systems should be comparable to or better than existing systems in terms of core flow capacity and flow efficiency. In fact, results from field evaluation of the fin-drain system at the Morris, Illinois, test site would indicate that the standard pipe envelope underdrain system should be improved to provide for better pavement performance. This can be accomplished by replacing the less permeable sand envelope with a more permeable coarse granular envelope material.

As for the fin drain, it is important that adequate flow below the freeboard area be maintained so that during periods of drainage the fin core will perform as a sink for water and not as a source of water to the structural pavement section. Based on subdrain outflow data obtained to date it would appear that a fin drain should have a flow zone capacity that will ensure that water flow in the fin section itself will not be in contact with structural pavement components for a period exceeding 2 hr. This study indicates that geocomposite fin-drain systems will be required to provide flow zone capacities in excess of 150 gal/hr at 0 percent pavement gradient and in excess of 200 gal/hr at gradients of 1 percent or greater to compare with a standard pipe and sand envelope system. When compared with a more permeable aggregate envelope system or a high-performance fin-drain system, flow zone capacities in excess of 200 gal/hr to 300 gal/hr may be desirable depending upon the pavement gradients and the number and size of joint and crack openings. Faulting data shown in Figures 18 and 19 would indicate performance advantages in designing a subdrainage system toward the higher values of core flow capacity.

When selecting a geocomposite fin-drain material for subdrainage applications, it is important to ensure that its structural properties meet design specifications in addition to meeting flow volume requirements. It is further recommended that fin-drain materials that use a loose-wrapped fabric not bonded to the core projections be used with caution since there is a high probability of fabric sag into the core and subsequent decrease in drainage efficiency.

Any new fin-drain material should be carefully evaluated to ensure that its projected core flow capacity and drainage efficiency will be equivalent to or exceed present systems. There still remain too many unknowns in the drainage area to not select subdrainage systems that are conservative or have a factor of safety in favor of the design engineer and good pavement performance.

In time it is felt that even better fin-drain systems and pipe envelope systems will be developed which will improve pavement performance. Until these are developed, it is important that pavement drainage not be compromised. Fin-drain materials for pavement edge drainage systems should be selected based on performance attributes as well as material and construction costs.

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REFERENCES

1. *AASHTO Guide for Design of Pavement Structures*. NCHRP Project 20-7/24. National Cooperative Highway Research Program and AASHTO Joint Task Force on Pavements, Washington, D.C., 1985.
2. B. J. Dempsey. Laboratory and Field Studies of Channeling and Pumping. In *Transportation Research Record 849*, TRB, National Research Council, Washington, D.C., 1982, pp. 1–12.
3. J. H. Woodstrom. Concrete Pavement Drainage in California. Presented at International Seminar on Drainage and Erodibility at the Concrete Slab-Subbase-Shoulder Interfaces, Laboratoire Central des Ponts et Chaussées, Paris, France, 1983.

4. M. I. Darter, J. M. Becker, M. B. Snyder, and R. E. Smith. *NCHRP Report 277: Portland Cement Concrete Pavement Evaluation System—COPES*. TRB, National Research Council, Washington, D.C., 1985, p. 175.
5. I. H. Shames. *Mechanics of Fluids*. McGraw Hill, Inc., New York, 1982.
6. B. J. Dempsey and Q. L. Robnett. Influence of Precipitation, Joints, and Sealing on Pavement Drainage. In *Transportation Research Record 705*, TRB, National Research Council, Washington, D.C., 1979, pp. 13–23.

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