Synthesis on Subsurface Drainage of Water Infiltrating a Pavement Structure
SYNTHESIS ON
SUBSURFACE DRAINAGE OF WATER
INFILTERATING A PAVEMENT STRUCTURE

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I. INTRODUCTION

"When a pavement is filled with water, heavy vehicle loads cause severe damaging actions such as erosion and pumping, disintegration of cement-treated bases, stripping of asphalt coatings from bituminous-treated bases and subbases, and over stressing of weakened subgrades. Also, the mere presence of abundant water causes or accelerates numerous non-load bearing actions such as "D"-cracking, blow-up, frost action, expansion, shrinkage cracking, increased oxidation and loss of flexibility, and general deterioration of wearing courses and stabilized bases. (1)"

"Pavements designed without rapid internal drainage can remain filled with water a number of days or weeks after each saturating rainfall, adding up to several months of damaging environmental conditions each year. When good internal drainage is provided, however, the water-related damages can be eliminated or at least greatly reduced. (1)"

The main source of moisture in a pavement structure is surface water infiltrating through cracks, transverse and longitudinal joints (especially the lane/shoulder joint), granular shoulders, and interconnected voids in the pavement (Figure 1). Surface water infiltration can account for as much as 90 to 95 percent of the total moisture in a pavement system. Other sources of moisture include capillary water and water vapor rising through subgrade soils, frost lenses melting during the spring thaw, and groundwater from localized springs and interrupted aquifers.

Figure 1 Moisture Entering A Pavement Structure
Because it is difficult and expensive to stop all moisture from entering the pavement structure, subsurface pavement drainage systems are used to intercept and quickly remove water from the pavement structure. In order to minimize moisture related distresses, unbound bases and subbases should be drained to less than 85 percent of saturation as quickly as possible (less than five hours), especially on high volume roads with trucks (2). Also, infiltration should be removed from the pavement structure before reaching the subgrade where it reduces the support strength of the soil. In either case, subsurface pavement drainage can only remove free water that responds to gravity.

Part II of this report lists factors and conditions that dictate or limit the effectiveness of subsurface drainage. Part III describes the components used in various drainage systems. Part IV discusses various combinations of drainage components used to form drainage systems for particular applications. Part V discusses inspection and maintenance activities, as well as records kept for drainage systems. Part VI summarizes findings of a survey sent to Minnesota city and county engineers on their use of subsurface drainage. Finally, Part VII presents cost and performance data for drainage systems used by various state agencies.

II. PAVEMENT STRUCTURES AND ENVIRONMENTAL CONDITIONS THAT LIMIT BENEFITS OF SUBSURFACE DRAINAGE

This section gives a general indication of the expected effectiveness or benefit of subsurface drainage systems based on the following factors: environmental conditions, pavement layer composition, pavement condition, pavement age, roadway alignment, existing drainage, and traffic conditions.

Subsurface pavement drainage normally provides no additional benefit to a pavement if any of the following conditions exist:
- pavement is structurally inadequate;
- average annual rainfall is less than ten inches (3);
- lateral and vertical drainage in the pavement section exceed infiltration (3);
- permeability of the subgrade exceeds 50 ft/day (4); or
- predicted Equivalent Standard Axle Loads per day is less than 250 for a rigid pavement (3).

Subsurface pavement drainage may be beneficial but not cost effective for an existing pavement if any of the following conditions exist:
- pavement is in advanced stages of deterioration or has more than minimal cracking;
- rigid pavement is over ten years old (5);
rigid pavement has more than 10 percent of the panels having one crack or more than one percent of the panels having connected multiple cracks (5); or
rigid pavement has more than 13 million accumulated Equivalent Standard Axle Loads (5).

Subsurface pavement drainage could actually accelerate pavement distress if any of the following conditions exist:
- granular bases contain 25 percent or greater amount of material passing the No. 200 sieve (5);
- pavement section is in a low area where it is impossible to provide free flowing (positive) outlets for water that would be collected by a subsurface drainage system (4); or
- longitudinal grade is extremely flat and it is impossible to place drainage components at a sufficient gradient to ensure flow in the pipe.

III. COMPONENTS OF VARIOUS SUBSURFACE PAVEMENT DRAINAGE SYSTEMS

The main components used in subsurface drainage systems include; highly permeable base drainage layer, base/filter layer under the drainage layer, longitudinal collectors in the pavement structure, transverse collectors in the pavement structure, and outlet pipes.

A. Highly Permeable Base Drainage Layer

Generally the drainage layer is a minimum of three to four inches thick, highly permeable material that extends under the full width of the roadway exposed to traffic loads. The drainage layer, also referred to as a drainage blanket, horizontal drainage blanket, or a drainable layer, uses highly permeable material to allow quick lateral drainage even though the cross slope of the layer is very low and the thickness of the layer is limited.

While the drainage layer usually is located just above the subgrade (Figure 2), some agencies are placing the drainage layer above the base (Figure 3). Placement next to the subgrade allows the entire pavement structure to be drained, but it can allow moisture to dampen the subgrade. Placement above the base does a better job of quickly removing water from melting frost and prevents infiltration from reaching the subgrade; however, drainage of the base and subgrade are limited.
Although relatively pervious granular materials are often used for base and subbase courses, these layers will not function as drainable layers unless they are specifically designed and constructed to do so. (6) Generally, the gradation of these materials limit the permeability to very low values (less than 2 ft/day); an ideal drainage layer should have permeability in excess of 1000 feet per day.

Drainage layers with permeability well below 1000 feet per day are less than ideal for two reasons. First, they do not provide quick lateral drainage under low hydraulic gradients. Second, they are susceptible to plugging with fines.

Drainage layers with permeability greater than 3000 feet per day are also less than ideal. First, the aggregate is usually one-sized making it unstable unless asphalt or cement stabilization is used. Second, the material is difficult to compact. Third, high interparticle contact stresses that develop during dynamic traffic
Loadings degrade the aggregate producing fines that can decrease the permeability and plug the drainage layer over time.

Drainage layers with permeability in the range of 1000 to 3000 feet per day are the most ideal for the following reasons. First, the aggregate can be well graded to provide adequate stability during placement and compaction without using asphalt or cement stabilization. Second, the gradation requirements can usually be met by single run crushing operations without any additional screening or blending.

However, a major problem even with moderately permeable aggregate is that it has a tendency to segregate during placement and compaction. Segregation can create pockets of fines that cause differential heave and/or frost heave. Control of segregation and improved stability can be obtained in several ways:

- special construction procedures and equipment can be used so that segregation and stability are not a problem;
- stability often can be increased with minor adjustments in gradation without seriously affecting the permeability (except when adjusting the amount of fines); and
- permeable materials can be treated/stabilized with either asphalt or cement.

Generally, permeable materials do not require stabilization if construction equipment does not travel on the material. However, the material may be stabilized to increase the layer's strength and provide a good working base for final surface placement. Approximately two percent asphaltic stabilization or water cement ratio of approximately 0.4 for cement stabilization are typical, with granular equivalents of 1.4 and 1.7, respectively.

Stabilized or not, the permeable materials are not usually compacted to a specified density. Instead, the materials are generally rolled with non-vibratory rollers to "seat" the material. It is desirable to compact the material to maximize the structural potential of the layer and to prevent any additional compaction from traffic loadings (rutting).

Some general specifications/guidelines for permeable base aggregate are as follow:
- use crushed aggregate since crushed material is more stable than natural, rounded aggregate;
- limit maximum size aggregate to prevent material degradation from high interparticle contact stress;
- do not use degradable materials, which over time decrease the permeability of the drainage layer; and
- use caution with crushed recycled concrete and certain slag-type materials that may produce a precipitate which can plug drainage systems.
B. Base/Filter Layer Under the Drainage Layer

"It has long been recognized that, when water flows from a fine grained soil into a coarser one, there is a tendency for particles of the finer soil to be washed into the voids of the coarse soil. This can lead to clogging and an overall reduction in permeability. It has also been established that this tendency for intrusion of fines into the pores of a granular material can be initiated or aggravated by the pumping action caused by the repetitive loading of traffic. (6)"

"Therefore, in order to protect the drainage layer from intrusion of fines the supporting layer must satisfy certain filter criteria. If these criteria are not satisfied by the existing support layer, then a protective filter must be designed and placed between the fine and coarse soils to prevent intrusion and clogging. Commonly, this protective filter consists of a layer of granular soil whose gradation and other characteristics satisfy established filter criteria. However, in recent years a number of different types of drainage fabrics and mats have become available and have been used for this purpose (6)." Also, some agencies are starting to use cement or lime stabilized subgrades in place of a filter layer, especially on large paved areas like parking lots and airport runways.

Filter material, whether granular or fabric, must meet three general requirements:
- it must prevent finer material, usually the subgrade soil, from piping or migrating into the drainage layer without clogging with suspended particles;
- it must be permeable enough to allow water to pass without any significant resistance or build up of hydrostatic pressure; and
- it must be strong enough to carry the loads applied and, for aggregate filters, to distribute live loads to the next layer (5).

There are three types of filter fabric (knitted, woven, and non-woven), all of which can be used satisfactorily if they meet the design requirements (5). Generally, the fabric must be tough enough to remain intact during construction, remain chemically stable in the roadbed over the design life of the road, and have an equivalent opening size compatible with both the supporting soil and the drainage layer.

Filter fabric has the advantages of versatile placement in the pavement structure, rapid installation, and generally lower cost than granular filters. The disadvantages with filter fabric include its tendency to act like a wick which retains moisture and its tendency to plug if adjacent to materials with a high amount of fines.
Granular filters have been used for a long time, and they perform well if properly constructed. "Although it is possible to design relatively thin granular filters using filter design criteria, it is recommended for practical purposes that the filter be no less than three inches thick. (6)"

The advantages of a granular filter include its low permeability preventing infiltration from reaching the subgrade, lower susceptibility to plugging, and lower moisture retention than fabric filters. The disadvantages of granular filters include more difficult installation and less versatile placement in the pavement structure compared to fabric filters.

C. System of Longitudinal Collectors in the Pavement Structure

A system of longitudinal collectors is used to remove water from a drainage layer and/or the aggregate trench surrounding the collector and quickly convey it to suitable outlets along the roadway. Daylighting of drainage layers or aggregate trenches into the side slope of a roadway is not recommended because:
- the drainage layer is hard to compact and does not develop good strength unless confined,
- the daylighted layer or trench can allow rapid infiltration into the pavement layers, and
- it is difficult to keep the daylighted material from plugging with debris.

The design of longitudinal collectors must consider the type, location, slope, and size of collector as well as make provisions for adequate filter protection for the collector system.

1. Type of Collector

The collector usually consists of a slotted or perforated pipe or conduit. Most of the newer drainage conduits are flexible rather than rigid like the clay, concrete, or metal conduits used previously for drainage systems. The pipes must have good load-deflection characteristics and impact resistance to withstand installation and dynamic traffic loadings, they must be chemically resistant to corrosive conditions that may exist, and they must be durable.

2. Location of the Collector

Horizontal placement of the collector in the pavement cross-section must take into account whether the shoulder is to be drained. Placement can range laterally from the pavement/shoulder joint to the outer edge of the shoulder. Placement at the pavement/shoulder joint prevents water accumulation and pumping at this critical location in the pavement support, while placement at the outer edge of the shoulder allows drainage of both pavement and shoulder
support. However, placement at the outer edge of the shoulder increases the drainage path length for the pavement support and therefore the drainage time.

Vertical placement of the collector must take into account the depth of frost penetration, cost of deep placement, and height of the water table. In areas with no significant frost penetration, the collectors are placed as shallow as one foot deep, while areas with significant frost penetration require deeper placement. With shallow placement, there must be adequate material above the collector to protect it from traffic loadings, and the collector must be deep enough to prevent water in the collector from flowing into the pavement structure being drained. The deeper the collector is placed the more expensive; therefore, cost will sometimes control the depth of the collector. Generally, separate drainage systems are used to control high water tables because deep placement of collectors increases drainage path length and time for the critical pavement surface and base exposed to traffic loadings.

3. Slope of the Collector

The longitudinal slope of the collector system normally follows the longitudinal grade of the road. However, practical construction and operational factors dictate that slopes of collector pipes should not be less than one percent for smooth bore pipes and two percent for corrugated pipes. (6) Therefore, in areas with very flat grade, the depth of the collector pipe below the pavement surface may have to vary to meet minimum grade requirements.

4. Size of the Collector

Most agencies currently use four inch diameter perforated or slotted plastic or PVC pipe. However, other shape plastic conduits with equivalent capacity are becoming more common. The four inch pipes are normally oversized for the capacity required with typical outlet spacing and longitudinal collector slope.

5. Filter Protection for the Collector

The final consideration for the collector system is adequate filter protection. The filter must prevent soil and aggregate from plugging the collector, but at the same time must not significantly restrict flow into the collector which could back up water in the pavement structure. Generally, the filter design criteria used for the filter between the drainage layer and its supporting layer applies to the filter for protecting the collector as well.
D. System of Transverse Collectors in the Pavement Structure

Subsurface collectors that run laterally beneath the roadway are classified as transverse drains or cross drains. These drains are usually located at right angles to the roadway centerline although in some cases they may be skewed (3). Transverse collectors have to be carefully designed and constructed; especially in areas with significant frost penetration where differential heave could result from any discontinuity in the longitudinal profile of the road.

Transverse collectors have four typical applications. First, they are used on pavement sections with steep (greater than four percent) grade to limit both longitudinal seepage distance under the pavement and buildup of hydrostatic head (Figure 4) (9). Second, they are used to drain moisture trapped by impermeable barriers that extend below the normal pavement structure. Such barriers include abrupt changes in pavement depth, bridge approach slabs, and pavement end anchors. Third, transverse collectors are used to control moisture from springs and other localized water sources. Fourth, transverse drains are used directly below each joint in jointed concrete pavements to intercept moisture entering the pavement at this critical location (Figure 5).

![Figure 4](image-url)
The level of drainage and length of service from transverse drains is highly dependent on the method of installation. The best, but also the most expensive installation, is the use of an aggregate filled trench surrounding the drain pipe. This type of installation will provide quicker drainage and longer service than installations where the drain pipe is plowed in or inserted under the pavement surface using special equipment. Generally, the design criteria used for aggregate trenches and filter protection on longitudinal drains also applies to transverse drains.

Three differences for transverse drains versus longitudinal drains include the following. First, transverse drains can be connected to either a longitudinal collector or directly to an outlet pipe for discharging water. Second, transverse collectors normally follow the cross slope of the pavement. Third, transverse drains can be installed from the shoulder area with special equipment that force drains into the roadbed under a pavement without disturbing the pavement surface.

E. Outlet Pipes

Outlet pipes are used to provide free drainage of water collected by longitudinal and transverse collectors to a ditch, storm sewer, catch basin, or other surface drainage facility outside the pavement structure. The pipes are typically four inch diameter solid wall pipe connected to the collector pipe with a 45 to 90 degree angle from down stream flow in the collector pipe. The connection should have at least a 12 inch radius bend for easy insertion of cleaning equipment. The minimum slope of the outlet
pipe should be greater than that of the collector or at least three percent (5).

The open ends of outlets should be at least six to twelve inches above ditch flow line and should be protected by a headwall or splash block that conforms to the ditch slope. The headwalls, either cast-in-place or precast, protect the exposed pipe from vehicles and also keep grass and weeds from hindering flow from the pipe. Most agencies also specify that the open end of outlet pipes be protected with hinged or removable rodent guards. The guards must be removable because the outlets will usually require some maintenance to keep them free flowing (Figure 6).

![Figure 6](image)

As a general rule, the spacing of outlets should not exceed 300 feet. Normally this spacing will easily discharge the quantity of water picked up by the collector system. If the spacing of the outlets must exceed 300 feet due to topographical or geometric features of the roadway, cleanouts should be installed every 200 to 300 feet for cleaning and maintenance purposes.

Short posts visible from the roadway or markings on the pavement surface should be used to mark the exposed end of outlet pipes. The markers make locating outlets easier for mowing around, and also for inspecting and maintaining the outlets.

IV. TYPES OF SUBSURFACE PAVEMENT DRAINAGE SYSTEMS

This section analyzes various combinations of the drainage components discussed in the previous section to form drainage systems with specific applications or desired levels of
performance. The various types of subsurface pavement drainage systems are typically classified by the components used, the geometry of the system, and whether the system is installed during new construction of a roadway or whether it is retrofit into an existing pavement structure.

A. Complete/Comprehensive Subsurface Pavement Drainage System

This system must be incorporated into the original design of a pavement section or major reconstruction of an existing pavement section. All the components listed in section III are used with the possible exception of transverse drains which are used only if required.

These systems are designed and constructed to intercept and quickly drain all free water entering the pavement structure.

B. Longitudinal Edgedrains

Longitudinal edgedrains, often known simply as edgedrains, are one of the most commonly used techniques in subsurface drainage. Edgedrains usually employ the following features: longitudinal collector (with or without an aggregate trench), outlet pipes, and possibly transverse collectors. Since installation of a drainage layer and its protective filter is not required, edgedrains can be incorporated into either old or new pavement sections. Installations on old pavements are commonly referred to as retrofit edgedrains.

Edgedrains are designed and constructed primarily to intercept and quickly remove infiltration coming through the pavement/shoulder joint in order to control pumping and ponding that occurs at this location. Identification of drainage paths in the pavement structure will determine proper placement of the trench and longitudinal collector for efficient drainage. Typically, horizontal trench placement ranges from the edge of the pavement to outside the shoulder, and vertical placement ranges from the top of the base layer to just below the subgrade.

The edgedrains will also intercept moisture that slowly drains towards the collector pipes through low permeability bases and subbases and along the surface/base interface. "Effective drainage of bases and subbases is strictly dependant on the permeability of these layers. For layers with permeability in the range of 25 to 250 feet per day, there will be some drainage, and for permeabilities greater than 250 feet per day, there will be appreciable drainage. (5)" "For unbound layers with permeability less than two feet per day, it may not be effective to use edgedrains since erosion of fines in the base may result in plugging of or loss of fines through the drainage system. (5)" This erosion of fines could even accelerate deterioration of a pavement due to loss of edge support for a pavement.
In addition to classification according to pavement age, edgedrains are further identified by the design of the longitudinal collector. The two most common longitudinal collectors are the aggregate trench/pipe system and the geocomposite fin drain system. Less common is an aggregate filled trench without a longitudinal pipe (various trench cross sections have been used). The main disadvantage of this system is the lack of a low resistance path to carry water to outlet structures. This increases the drainage time, especially in areas with flat grades.

1. Aggregate Trench/ Pipe System

The aggregate trench/pipe system is used on both new pavement structures and for retrofit on old pavement structures. Generally, a trench/pipe edgedrain consists of a four inch to six inch diameter perforated or slotted pipe placed in a six to twelve inch wide trench along the edge of the pavement (Figure 7). The trench is backfilled with sand or coarse aggregate envelope material, and may or may not be protected with a geotextile filter. If a filter is used it may be used to line the trench or it may be placed around the pipe depending on the gradation of the existing soil and backfill material used.

![Figure 7 Aggregate Trench/Pipe Drain](image)

The backfill or envelope material serves the following functions; prevents movement of soil particles into the drain pipe, provides material with higher permeability than the surrounding soil, and provides suitable bedding for the drain pipe. The permeability of the backfill varies greatly from agency to agency based on how fast
of drainage is desired. Some agencies use sand backfill with permeabilities as low as 50 feet per day, while other agencies use backfill with permeabilities exceeding 3000 feet per day. However, since it is difficult to compact non-cohesive material in the narrow drainage trench, some agencies use stabilized backfill to minimize surface settlement.

2. Geocomposite Fin Drain System

A geocomposite fin drain is the combination of a geotextile fabric wrapped around a structural plastic core, where the fabric serves as the filter and the voids created by the plastic core form the conduit for the water. Most agencies limit geocomposite fin drain systems to retrofit use because they are relatively new (use of fin drains in subsurface pavement drainage increased starting in 1983 (5)), and their extended performance has been questioned. However, this policy is changing as the fin drains become more cost competitive, and their extended performance is proven.

Fin drains are usually installed in one pass of a four to six inch wide trencher. The trenchers are usually equipped with an attachment that inserts the fin drain and a portion of the backfill immediately behind the trencher wheel or chain. Since the fin drains are placed in direct contact with the pavement and base edge, care must be used during installation to prevent undermining support for these layers. The top of the fin drain is placed slightly below the shoulder material where it can quickly intercept moisture infiltrating the pavement/shoulder joint (Figure 8).

"Since the fin drain functions both as a collector and 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. (7)" This prevents backflow of water from the core into the structural layers of the pavement (Figure 8).

"Now have a broad range of geocomposite fin products which 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. (7)"
Testing of these products will be required to insure the structural integrity of the core and fabric to maintain an adequate flow channel during construction and while in service. The core must have superior structural properties, chemical resistance, and long term durability. The fabric should be a high modulus geotextile with an average opening size in the 50 to 70 range (8). Fin drain materials with a loose wrapped fabric on an open core have a high probability of diminished core flow capacity because of fabric sag into the core (7), and they should not be used. An additional consideration when selecting geocomposite fin drains is to be sure a complete line of couplings, end caps, end outlets, and in-line outlet tees are available to complete the system.

With proper design, geocomposite fin drain systems will provide drainage capacity and field performance equivalent to or exceeding that of an aggregate trench/pipe system at a comparable cost. The main advantages of the fin drain over aggregate trench/pipe system include:

- easier installation
- narrower trench required
- able to use trench material as backfill (permeable backfill not required)
- typically easier to compact the trench backfill than the permeable aggregate material used with trench/pipe systems (less prone to settlement)
- faster installation (up to 90 feet per minute)
- higher flow velocities in the narrow core (compared to velocities in a circular pipe at an equivalent volume of flow) assist in self cleaning sediment from the core
- less prone to freeze up
- generally start flowing quicker in areas with significant frost penetration because they thaw from the top downward like the soil
- better at draining frost melt water trapped above frozen pavement structure or subgrade

C. Transverse Drains

Transverse drains, which are also known as localized surface drains, have to be used with outlet pipes, or they need to be connected to longitudinal edgedrains to discharge water collected.

These drains are typically used to correct isolated moisture problems, especially isolated springs or frost boils. However, the use of transverse collectors under the joints in concrete pavements is passing the experimental stages, and companies are starting to specialize in equipment and construction procedures to install the systems. These systems are being used on both new and existing concrete pavements.

V. INSPECTION, MAINTENANCE, and RECORDS

Even with proper design and construction subsurface drainage systems require some maintenance to keep them operating efficiently. It is expected that sediment will collect in the system due to inadequate gradients, uneven settlement of the system, and/or heavy sediment load (5). Also, the pavement surface and surface drainage features must be maintained to prevent excess infiltration that could exceed subsurface drainage system capacities. Such maintenance may include sealing cracks and joints to limit infiltration, maintaining proper cross slope to prevent ponding of water in the wheel paths or shoulder area, and maintaining ditches and culverts in a free flowing condition.

Inspection of subsurface drainage features should be made prior to seasonal periods of heavy rainfall as well as following particularly heavy rainfall events and/or at least once every three months (5). Maintenance of the subsurface drainage systems includes cleaning the collector pipes and outlets.

If inspection of the system indicates reduced efficiency, the collector can be flushed out using large quantities of clean water if proper cleanout facilities were installed. If the system has no cleanouts, it can be cleaned by back flushing or snaking a cleaning device through the outlet pipes. However, snake type cleaning devices will not work for most geocomposite fin drains.

With respect to the outlet pipes, the main concern is to prevent blockage of the pipe outlet due to siltation, plant growth, debris,
or mechanical damage from vehicles or animals. Typically, all that will be required is cleaning rodent screens on the ends of the pipe and clearing debris from the vicinity of the headwall or splash blocks. One other concern with the outlets is to maintain the outlet markers.

The following records should be kept for subsurface drainage systems:
- detailed as-built plans to facilitate any repairs that are required
- a listing of the location of drainage features (especially outlet pipes) so maintenance crews can easily locate them
- continuous inspection records for monitoring the system to determine the need for maintenance activities or modifications to the system or surface drainage features.

VI. MINNESOTA CITY AND COUNTY SURVEY ON SUBSURFACE DRAINAGE

Table One summarizes the results of a subsurface drainage survey sent to Minnesota city and county engineers on April 5, 1989. Following Table One are additional comments from the survey and several comparisons between the city and county work.
Table One: Survey Results - Subsurface Drainage for Minnesota City and County Agencies (10)

<table>
<thead>
<tr>
<th>Distribution of reasons for using drainage:</th>
<th>City</th>
<th>County</th>
</tr>
</thead>
<tbody>
<tr>
<td>* prevent saturation of base and subbase ..</td>
<td>17 of 25</td>
<td>12 of 32</td>
</tr>
<tr>
<td>* control frost boils or heave ............</td>
<td>12 of 25</td>
<td>22 of 32</td>
</tr>
<tr>
<td>* control springs or groundwater seepage ..</td>
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<td>23 of 32</td>
</tr>
<tr>
<td>* control pumping and ponding at edge joint</td>
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</tr>
<tr>
<td>* control flow under surface on steep grade</td>
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<td>4 of 32</td>
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<tr>
<td>* agencies not listing particular use .....</td>
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<table>
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<tr>
<th>Installation methods and size information:</th>
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<th>County</th>
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<td>- trench/tile .....</td>
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<td>- backhoe ........</td>
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<td>16 of 32</td>
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<td>* type of filter: - none .................</td>
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<td>- aggregate ........</td>
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</tr>
<tr>
<td>- fabric sock on pipe ...</td>
<td>8 of 25</td>
<td>10 of 32</td>
</tr>
<tr>
<td>- fabric liner on trench</td>
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<td>2 of 32</td>
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<td>- aggregate and fabric ..</td>
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<td>4 of 32</td>
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<tr>
<td>* pipe depth (d) in inches: - 0 &lt; d &lt; 12</td>
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<td>0 of 32</td>
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<tr>
<td>- pea rock ............</td>
<td>2 of 25</td>
<td>4 of 32</td>
</tr>
<tr>
<td>- rock ................</td>
<td>5 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- aggregate (no size)</td>
<td>7 of 25</td>
<td>8 of 32</td>
</tr>
<tr>
<td>- trench material ....</td>
<td>0 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- not specified .....</td>
<td>10 of 25</td>
<td>17 of 32</td>
</tr>
<tr>
<td>* pipe diameter (inches): - 3.0 ..........</td>
<td>0 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- 4.0 .............</td>
<td>7 of 25</td>
<td>11 of 32</td>
</tr>
<tr>
<td>- 6.0 ............</td>
<td>3 of 25</td>
<td>3 of 32</td>
</tr>
<tr>
<td>- 8.0 ............</td>
<td>1 of 25</td>
<td>0 of 32</td>
</tr>
<tr>
<td>- 10.0 ...........</td>
<td>0 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- not specified ..</td>
<td>14 of 25</td>
<td>16 of 32</td>
</tr>
<tr>
<td>* pipe design: - PVC - perforated .......</td>
<td>4 of 25</td>
<td>4 of 32</td>
</tr>
<tr>
<td>- slotted ............</td>
<td>1 of 25</td>
<td>0 of 32</td>
</tr>
<tr>
<td>- plastic - perforated ....</td>
<td>1 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- slotted ..........</td>
<td>0 of 25</td>
<td>2 of 32</td>
</tr>
<tr>
<td>- corrugated .......</td>
<td>0 of 25</td>
<td>3 of 32</td>
</tr>
<tr>
<td>Performance data:</td>
<td>City</td>
<td>County</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------</td>
<td>----------------</td>
</tr>
<tr>
<td>* system age (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 0 to 5</td>
<td>2 of 25</td>
<td>2 of 32</td>
</tr>
<tr>
<td>- 6 to 10</td>
<td>2 of 25</td>
<td>0 of 32</td>
</tr>
<tr>
<td>- 11 to 15</td>
<td>1 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- 16 to 20</td>
<td>2 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- not specified</td>
<td>18 of 25</td>
<td>28 of 32</td>
</tr>
<tr>
<td>* expected life (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 15</td>
<td>0 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- 20</td>
<td>4 of 25</td>
<td>3 of 32</td>
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<tr>
<td>- 25</td>
<td>2 of 25</td>
<td>0 of 32</td>
</tr>
<tr>
<td>- 30</td>
<td>0 of 25</td>
<td>1 of 32</td>
</tr>
<tr>
<td>- 50 plus</td>
<td>2 of 25</td>
<td>3 of 32</td>
</tr>
<tr>
<td>- not specified</td>
<td>17 of 25</td>
<td>24 of 32</td>
</tr>
</tbody>
</table>

Cost data for edgedrains:

<table>
<thead>
<tr>
<th>* city use ($/ft)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1.00 to 2.00</td>
<td>5 of 25</td>
</tr>
<tr>
<td>- 4.00 to 5.00</td>
<td>3 of 25</td>
</tr>
<tr>
<td>- 8.00 to 10.00</td>
<td>4 of 25</td>
</tr>
<tr>
<td>- 11.00 to 13.00</td>
<td>6 of 25</td>
</tr>
<tr>
<td>- 13.00 plus</td>
<td>1 of 25</td>
</tr>
<tr>
<td>- not specified</td>
<td>6 of 25</td>
</tr>
</tbody>
</table>

- average reported cost = $ 7.35
- standard deviation = 4.60

* county use ($/ft) -

| - 0.40 to 0.75    | 4 of 32        |
| - 0.76 to 1.50    | 10 of 32       |
| - 1.51 to 2.50    | 5 of 32        |
| - 2.51 to 3.50    | 2 of 32        |
| - 3.51 plus       | 4 of 32        |
| - not specified   | 7 of 32        |

- average reported cost = $ 2.98
- standard deviation = 4.01

General remarks taken from the city responses:
- Four reported drain connections into the sewer pipe, while three reported connections into catch basins.
- Two reported installing drains on both sides of the street.
- Two reported connection of sump pumps into the subsurface drainage.
- One reported placing the drain pipe in the same trench as the sewer pipe.
One reported cutting a V-trench using a roadgrader and filling the trench with aggregate without a pipe.
- One reported a preference for rigid verses flexible pipe.

General remarks taken from the county responses:
- Two reported installing drains on gravel roads.
- Three reported placing drains under the centerline of the road.
- One reported corrugated metal pipe rusting out in only eight years.
- Two reported the importance of good outlets and maintenance of the outlets.
- One reported placing an insulating material below the trench cap.

The following trends are representative of the survey responses:
- City agencies are placing drainage components deeper.
- City agencies are spending approximately 2.5 times as much per foot on drainage compared to the county agencies.
- City agencies more involved with keeping moisture out of entire length of a pavement, while county agencies are more involved with isolated moisture problems.
- City agencies are doing more in the way of filter protection of drainage components.

VII. COST AND PERFORMANCE DATA FROM VARIOUS STATE AGENCIES

As of 1987 forty percent of the states were experimenting with "new" or improved drainage systems, and ten percent of the states were using highly permeable open-graded drainage layers in their design of complete subsurface drainage systems (1).

With respect to edgedrains, many of the states have design specifications for both pipe/trench edgedrains and geocomposite fin drains. However, some states limit geocomposite fin drains to retrofit use only (use on existing pavements).

Only the cost of installing edgedrains without a drainage layer are given here for comparison with similar installations reported by the city and county agencies of Minnesota.

Ohio - pipe/trench drain - 1987 - $2.50 to $3.00 per foot
- fin drain - 1987 - $2.42 to $2.85 per foot (11)
Pennsylvania
- pipe/trench drain - 1982 - $8.70 per foot
Minnesota
- pipe/trench drain - 1988 - $1.25 per foot

The following quotes indicate the success states have had using subsurface drainage:
"Based upon published studies and individual case histories, an increase in service life of four years is believed to be
a conservative estimate for flexible pavements. An extension of service life of this magnitude will reduce pavement costs by approximately 19 percent. Similarly, studies of the effect of retrofit edgedrains on PCC pavement performance suggest an extension of service of 10 years, which equates into a cost reduction of 35 percent ... (4)"

"In 1979 the use of experimental edgedrains on three different continuously reinforced concrete projects in Illinois reduced the number of punch outs on an average of 24 percent. (4)"

"In 1984, a comprehensive six-state concrete pavement performance study ... concluded that provisions for subdrainage with edgedrains significantly increased the service life for jointed concrete pavement and jointed reinforced concrete pavement. (4)"

"The use of edgedrains on "D"-cracking susceptible pavements resulted in a large decrease in joint deterioration and pumping. (4)"

California Department of Transportation reported a decrease in faulting from 0.006 in/yr to 0.0003 in/yr on a plain jointed concrete pavement with a retrofit edgdrain, and a decrease in faulting from 0.002 in/yr to 0.0005 in/yr on new plain jointed concrete pavement with edgedrains (4).
REFERENCES


