U.S. Department of Transportation
Federal Highway Administration

CONSTRUCTION OF PAVEMENT SUBSURFACE DRAINAGE SYSTEMS
(REFERENCE MANUAL)

OFFICE OF PAVEMENT TECHNOLOGY
FEDERAL HIGHWAY ADMINISTRATION
DEPARTMENT of TRANSPORTATION

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AASHTO.....................American Association of State Highway and Transportation Officials

AC..Asphalt Concrete

ASTM..American Society of Testing Materials

BSOG...Bituminous Stabilized Open Graded

CALTRANS...California Department of Transportation

CPE...Corrugated Polyethylene

DGAB...Dense Graded Aggregate Base

FHWA...Federal Highway Administration

NCHRP...National Cooperative Highway Research Program

NEMA...National Electrical Manufacturer's Association

NHI...National Highway Institute

PCC...Portland Cement Concrete

PVC...Poly-Vinyl Chloride

PG...Performance Graded

SHA...State Highway Agency

VCR...Video Cassette Recorder

VDOT..Virginia Department of Transportation

1.0 INTRODUCTION

In 1988, the Federal Highway Administration (FHWA) conducted a field survey (Demonstration Project No. 975, Permeable Base Design and Construction) of ten States (California, Iowa, Kentucky, Michigan, Minnesota, New Jersey, North Carolina, Pennsylvania, West Virginia, and Wisconsin) to determine design criteria and construction problems for building permeable bases. Now there are approximately over 30 States using permeable bases.

Water in the pavement structure has long been recognized as a primary cause of distress. Within the past 5-10 years drainage of pavements has received an increasing amount of consideration. **The mechanics of moisture distress are somewhat different for Portland cement concrete pavements and asphalt concrete (flexible) pavements; however the basic theory for hydraulic drainage and pipe flow are the same regardless of the pavement type.**

The three major factors in moisture distress in pavements are listed below:

- Rainfall
- Heavy Trucks
- Pavement section

First, most of the United States experiences significant rainfall in the form of total annual rainfall or storms of heavy intensity over a short duration. This rainfall will infiltrate the pavement section through open joints or cracks in the pavement surface becoming infiltrated water in the pavement structural system. Since base material and sub-grades of existing roads are relatively impermeable, the trapped water will cause moisture distress in the pavement section.

Second, the wheel loads associated with heavy trucks will only become heavier as the size of trucks increase, and as truck traffic increases, the number of wheel load repetitions will increase accordingly.

Third, in reality, pavements engineers have no control over the first two factors. Pavement engineers only have control over the design and construction of the pavement section.

Detailed design guidance for design of both PCC and flexible pavement is provided in NHI Course No. 13126, **"Pavement Subsurface Drainage Design."** This workshop will focus on the construction of pavement drainage systems for both PCC and flexible pavements.

1.1 Portland Cement Concrete (PCC) Pavements

The primary source of free water is infiltration through cracks and joints in the pavement. A major source of infiltrated water is the longitudinal pavement/shoulder joint, particularly when flexible shoulders are used with rigid pavements. Water also enters the pavement section from shallow ditches and medians.

A list of moisture related distress for PCC pavements is provided in Table 1-1 (p. 2-14, Table 2.2, ERES, Reference Manual, NHI Course No. 13126, "Pavement Subsurface Drainage Design").

Below is a list of major distress in PCC pavements associated with excess water:

- Curling/warping
- Pumping
- Faulting
- Corner breaks
- Punchouts
- D-Cracking

Moisture distress in PCC pavements is a complex and progressive reaction.

Curling/warping During the daylight hours, the sun will heat up the surface of the concrete slab causing it to expand more than the bottom of the slab. This will tend to make the bow up in the middle. During the night, the process will reverse itself. Due to the cool night air the top of the slab will contract more than the bottom of the slab. This will tend to pull the ends of the slabs up. As these thermal cycles are applied to the slab, small voids under the pavement slab at the joints will be created.

Pumping As the pavement joints open up, water will enter the pavement section and collect in the voids. When heavy wheel loads approach the joint, the approach slab will deflect downwards sending a pressure wave or water jet towards the leave slab as shown in Figure 1-1. The approach slab then rebounds, and the leave slab is pushed downwards as the wheel crosses over the joint.

This churning action results in the erosion of material under the leave slab with some material being deposited under the approach slab, and the remainder of the material being pumped up though the pavement joint. Ejection of free water and this material is called pumping.

Faulting Material pumped from the pavement section is usually visible as stains on the pavement and shoulder. As the material builds up under the approach slab, the difference in elevation between the approach slab and leave slab is called faulting.

Corner Breaks The relocated material under the approach is relatively loose; there is definite loss of support under the approach slab and eventually there will be a triangular corner break. As the PCC pavement continues to lose support, additional cracks will develop until the pavement has completely failed and needs replacing.

For the purpose of this manual, it is assumed that pavement subsurface drainage systems are provided to combat the pumping problem in PCC pavements.

D-cracking D-cracking of concrete pavements is a moisture related distress and is caused by freezing and thawing of moisture in saturated aggregates which causes the aggregate to fracture.

Punchouts Punchouts are sections of CRCP that become surrounded by cracks that completely separate the punchout piece from the concrete slab. These pieces are usually somewhat rectangular in nature. Permeable bases are not recommended for CRCP pavements since any intrusion of the concrete into the permeable base will change the pavement design.

Factors for Pumping

One of the primary distress mechanisms observed on PCC pavements is pumping. Four conditions must exist beneath the pavement slab for pumping to occur (FHWA 1992):

- Free water
- Heavy wheel loads
- Erodible bases
- Voids

Unfortunately, all of these conditions are present on the vast majority of PCC pavements designed and constructed to date.

The merit of a permeable base is that it drains water in the base and does not allow the base to become saturated. Properly designed and constructed permeable bases do not develop the water pressure required for pumping to occur.

Other PCC Pavement Elements

Tied Concrete Shoulders or Widened Lanes

As the PCC pavements ages, the joint between the concrete pavement and the asphalt concrete shoulder will tend to open up. Since the materials are dissimilar, significant amount of water can enter the pavement structural system. To combat this, tied concrete shoulders are suggested. Since the pavement and shoulder materials are similar, and the shoulder is tied, or widened lanes provided, pavement infiltration is be reduced.

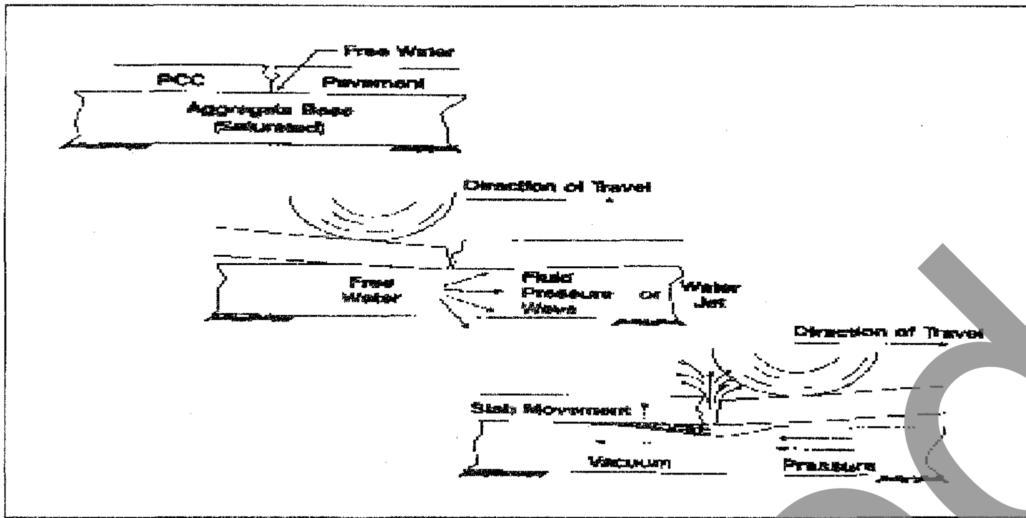

Figure 1–1 Moisture Related Distress in PCC Pavements

Tied concrete shoulders and widened lanes provide considerable edge support for the main concrete pavement slab. Since the edge of the slab is a critical stress area for PCC pavements, the pavement life should be extended.

Table 1 – 1 Moisture Related Distress in PCC Pavements

Type	Distress Manifestation	Moisture Problem	Climatic Problem	Materials Problem	Load Associated	Structural Defects Begins in		
						PCC	Subbase	Subgrade
Surface Defects	Spalling	Possible	Freeze Thaw Cycles	Mortar	No	Yes	No	No
	Scaling	Yes	Freeze Thaw Cycles	Chemical Influence	No	Yes Finishing	No	No
	D-Cracking	Yes	Freeze Thaw Cycles	Aggregate Expansion	No	Yes	No	No
	Crazing	No	No	Rich Mortar	No	Yes Weak Surface	No	No
Surface Deformations	Blow-up	No	Temperature	Thermo Properties	No	Yes	No	No
	Pumping and Erosion	Yes	Moisture	Inadequate Strength	Yes	No	Yes	Yes
	Faulting	Yes	Moisture - Suction	Erosion Settlement	Yes	No	Yes	Yes
	Curling/ Warping	Yes	Moisture and Temperature	Moisture and Temperature Differentials	No	Yes	No	No
Cracking	Corner	Yes	Moisture	Cracking Follows Erosion	Yes	No	Yes	Yes
	Diagonal Transverse Longitudinal	Yes	Moisture	Follows Erosion	Yes	No	Yes	Yes
	Punch-out (CRCP)	Yes	Moisture	Deformation Follows Cracking	Yes	No	Yes	Yes

Figure 1-2 shows a typical cross section of a PCC pavement. Discussions in this paper are based on this cross section

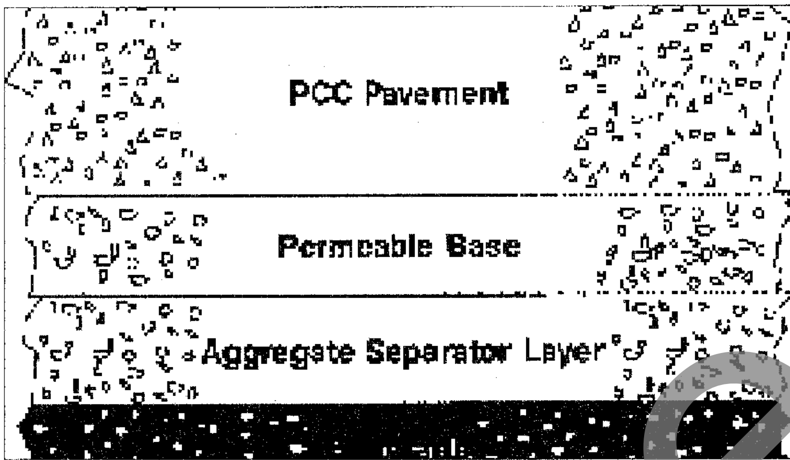

Figure 1 - 2 Typical PCC Pavement Cross Section

Dowel Bars

Dowel bars are the single most cost effective element that can be provided in a PCC pavement. Pavement subsurface drainage would be a second. Dowel bars provide load transfer from one slab to the other as the wheel load approaches the pavement and will help to bridge any void spaces that develop at the pavement joint.

1.2 <u>Asphalt Concrete (flexible) Pavements</u>

Moisture Related Distresses in AC Pavements

Moisture and soil subgrade support play an even more important role in AC pavements, since they are flexible pavements that transmit much greater stresses to the subgrade. Moisture damage to AC pavements can best be described by the following statement (p. 2-13, ERES, Reference Manual, NHI Course No. 13126, "Pavement Subsurface Drainage Design"):

"Moisture-damage occurs chiefly because of the influence of moisture on the load-carrying capacity of subgrades and its ability to degrade AC stabilized materials. The classical pavement design methods are based on saturated subgrade strength and the resulting loss of support due to excessive moisture. Pulsating pore pressures that develop in a subgrade as a result of moving loads significantly influence the subgrade's load carrying capacity".

<u>Stripping</u> Stripping is the gradual deterioration of the asphalt cement that binds the aggregate material together.

<u>Rutting</u> Rutting is a depression in the wheelpath of the pavement surface. This distress is due to a combination of heavy wheel load and excess moisture in the subgrade.

Alligator or fatigue cracking Alligator or fatigue cracking is the most common type of AC pavement distress. Alligator cracking is caused by repeated heavy wheel loads on the pavement and is accelerated by any excess moisture in the pavement structure.

Potholes Potholes are the terminal distresses for flexible pavement; they represent a complete failure of the pavement structure. This distress is an extension of alligator cracking in which moisture has penetrated the cracks and destroyed the pavement structure.

Crack deterioration Any transverse or longitudinal cracks that develop are quite similar to cracks in concrete pavements. Any excess moisture in the pavement structure will accelerate pavement deterioration.

A list of moisture related distress for AC pavements is provided in Table 1-2 (p. 2-14, Table 2.2, ERES, Reference Manual, NHI Course No. 13126, "Pavement Subsurface Drainage Design"). Note that the bump, rutting, depression, and pothole distresses begin at the subgrade level. Also note that excess moisture will accelerate almost every distress listed in the table.

Table 1 – 2 Moisture Related Distress in AC Pavements

Type	Distress Manifestation	Moisture Problem	Climatic Problem	Materials Problem	Load Associated	Structural Defects Begins in		
						AC	Base	Subgrade
Surface Deformation	Bump or Distortion	Excessive Moisture	Frost Heave	Volume Increase	No	No	No	Yes
	Corrugation or Rippling	Slight	Moisture and Temperature	Unstable Mix	Yes	Yes	Yes	Yes
	Stripping	Yes	Moisture	Loss of Bond	No	Yes	No	No
	Rutting	Excess in Granular layers or subgrade	Moisture	Plastic Deformation, Stripping	Yes	Yes	Yes	Yes
Cracking	Depression	Excess Moisture	Suction & Materials	Settlement, Fill Materials	No	No	No	Yes
	Potholes	Excess Moisture	Moisture, Temperature	Strength – Moisture	Yes	Yes	Yes	Yes
	Longitudinal	No Accelerates	No	Construction	No	Faulty Construction	No	No
	Alligator Fatigue	Yes Accelerates	Spring Thaw Strength Loss	Thickness	Yes	Yes Mix	Yes	No
	Transverse	No accelerates	Low Temperature F-W Cycles	Thermal Properties	No	Yes Temp. Susceptible	No	No
	Slippage	Yes	No	Loss of Bond	Yes	Yes Bond	No	No

Moisture distress in flexible pavements is shown in Figure 1-3. First, the pavement section has become saturated due to the infiltration of surface water. Next, as the moving wheel load proceeds down the pavement, it creates a moving pressure wave that forces the water deeper into

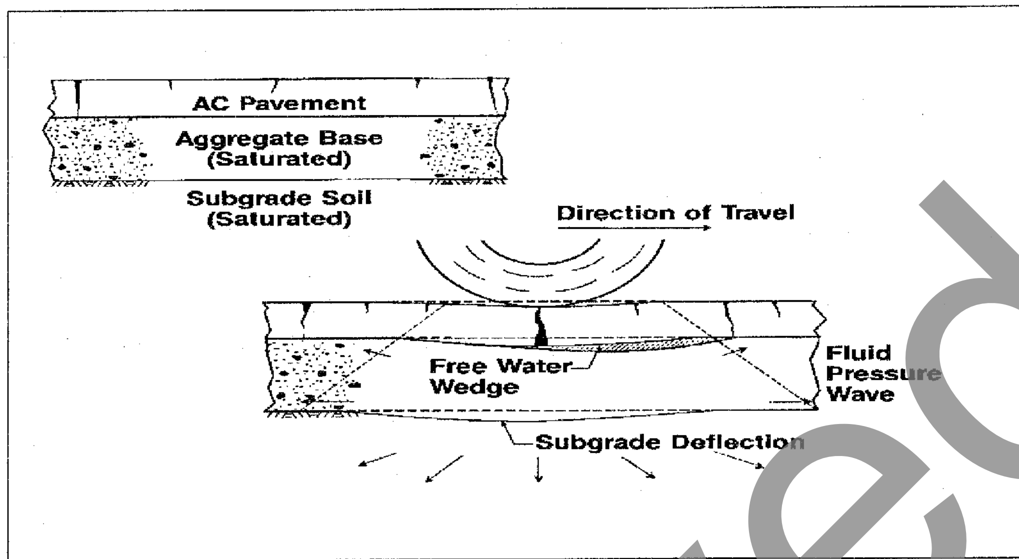

Figure 1 – 3 Moisture Distress in Flexible Pavements

the subgrade; thus further weakening the subgrade. Weakened subgrade is caused by excessive water it the subgrade and plays a large role in flexible pavement deterioration. Figure 1-4 shows a typical cross section of a flexible pavement. Discussions in this manual are based on this cross section. For graphical purpose, since a flexible pavement can be comprised of several layers, flexible pavement is shown as one layer in symbol form.

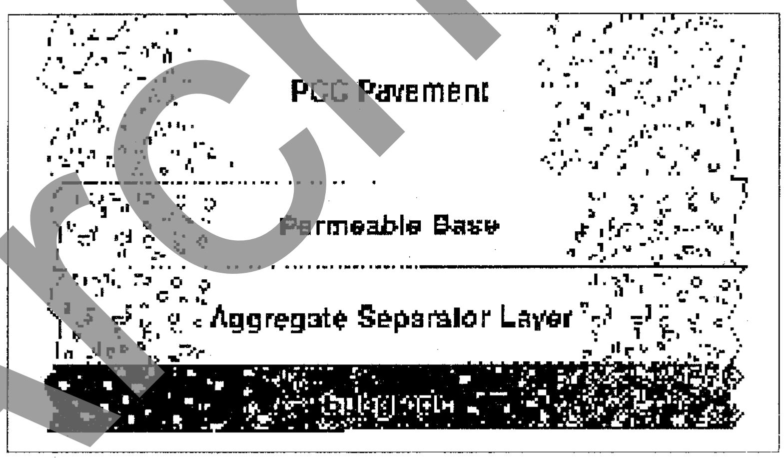

Figure 1 – 4 Typical Flexible Pavement Cross Section

1.3 Moisture Reduction Plan

To reduce water in the pavement section, the following approaches are recommended:

- Maintain effective joint and crack seals
- Provide drainable pavement systems

Previously, it was shown that considerable water will infiltrate the pavement shoulder joint for PCC pavements. As a pavement ages all joints and cracks, for both PCC flexible pavements, will tend to open up letting more infiltrated water into the pavement section. **All cracks and joints should be sealed to keep this water out.**

Unfortunately, some of the water will infiltrate into the pavement structural system. **Pavement subsurface drainage systems should be provided to remove this water.**

1.4 Drainage Elements

New or totally reconstructed pavements are excellent opportunities for constructing drainable pavement systems since permeable bases can be provided. Drainable pavement systems remove infiltrated surface water which cannot be prevented from entering the pavement structure. Drainable pavement systems consist of the following elements:

- Permeable bases
- Separator layer
- Edgedrain system

These elements are shown in Figure 1-5. Each of these elements must be properly designed so that there is no weak link in the drainage system.

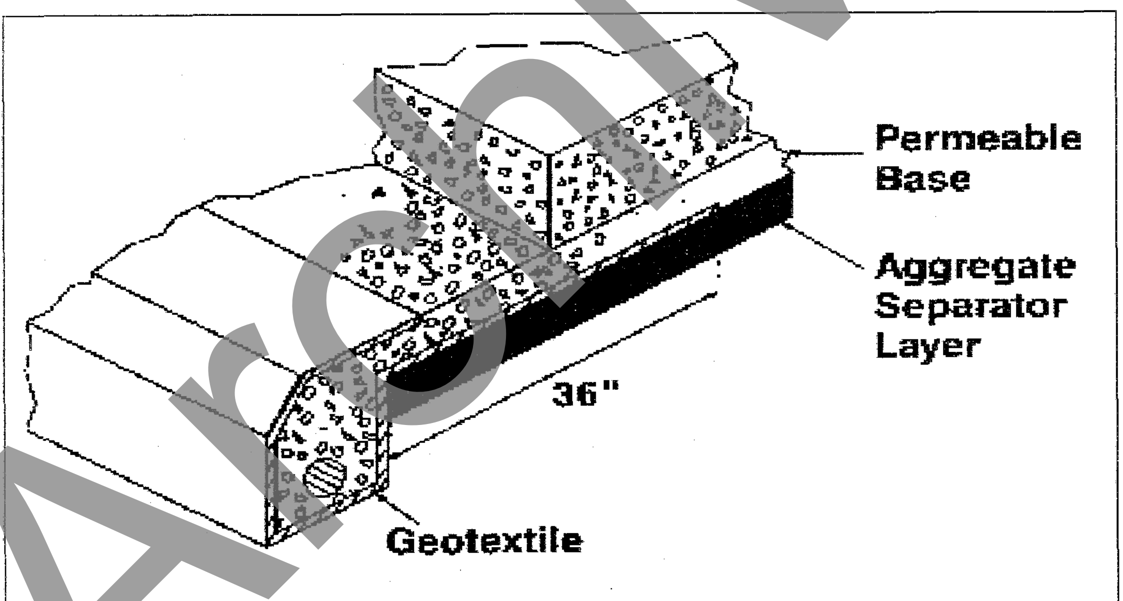

Figure 1-5 Drainable Pavement Systems Elements

A permeable base must provide both permeability and stability. Aggregate materials for permeable bases must be hard, durable, angular material with good aggregate interlock. Aggregate gradations must be carefully selected to provide both permeability and stability. Permeable bases can be constructed using both unstabilized and stabilized materials. Both asphalt and cement stabilized bases have been successfully constructed when the proper amount of stabilizer and construction practices are used. Proper compaction is essential to seat the permeable base.

The separator layer between the permeable base and subgrade is equally important as the permeable base. An aggregate separator layer or geotextile must be provided so that fines from the subgrade are not pumped up into the permeable base.

Daylighting the permeable base layer is not recommended since the daylighted layer is subject to clogging from roadway debris and vegetation (FHWA 1992). In addition, daylighted layers may allow silty material or storm water from the ditches to enter the pavement structure.

A longitudinal edgedrain collector system with outlet pipes to roadside ditches should be provided to insure positive drainage.

2.0 PERMEABLE BASES

2.1 General

From the start, State highway agencies (SHA's) recognized that permeable base designs must be a careful balance of permeability and stability of the base material. Efforts to solve this problem developed into two approaches. First, some SHA's used their existing dense-graded aggregate base gradations by removing some of the fines to produce the necessary permeability. Second, other SHA's used the highest permeability that could be obtained with readily available materials. These efforts resulted in two types of permeable bases: **unstabilized, and stabilized.**

Unstabilized bases consist of aggregate gradations that contain finer sized aggregates. **These bases develop their stability by good mechanical interlock of the aggregates.** Stabilized bases are more open-graded and thus much more permeable. **Stability is developed by the cementing action of the stabilizer material at the point of aggregate contact.** Placing concrete pavement on a permeable base is shown in Photo No. 1.

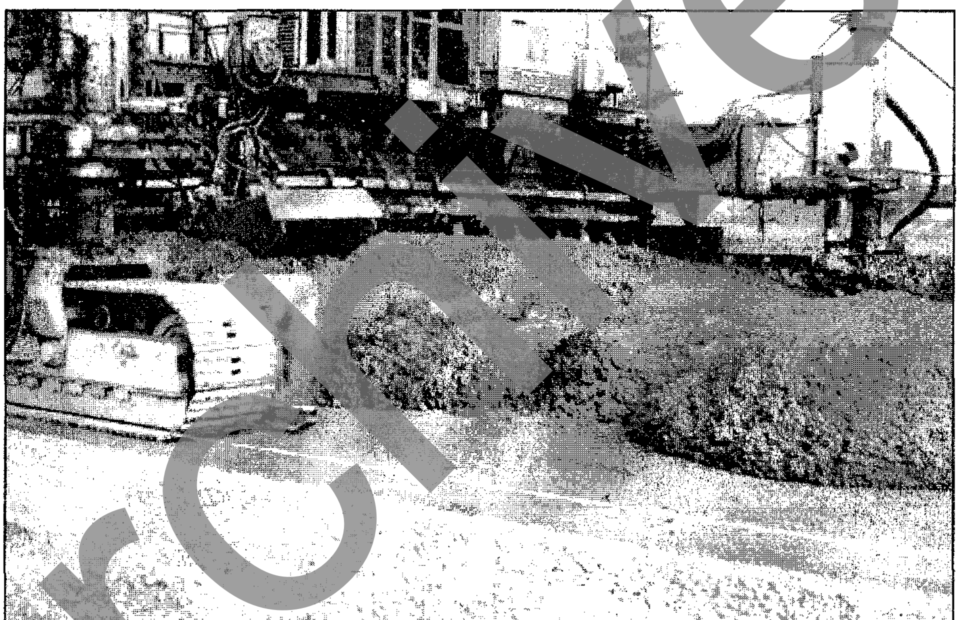

Photo No. 1 Placing Concrete Pavement on Permeable Base

The combination of base thickness and permeability must be capable of handling the design flows and keeping the saturation time to a minimum. **Draining 50 percent of the drainable water in 1-hour is recommended as a criterion for the highest-class highways, while draining 50 percent of the drainable water within 2-hours is recommend for most Interstate highways and roads (FHWA 1992).**

The permeable base must provide the following three functions

- Adequate permeability.
- Enough stability to support paving operation.
- Necessary strength for the pavement structural design.

2.2 Pavement Section

There are a number of choices that make development of the pavement section difficult. These choices are:

- Material type - (unstabilized or stabilized)
- Separator layer type - (aggregate or geotextile)
- Edgedrain location
- Pre, or post installation of edgedrain
- Pavement cross slope - (uniform cross slope or crowned)
- Shoulder type - (similar or dissimilar materials)

Material Type - The first and most important choice is the use of stabilizer material.

- Unstabilized - Unstabilized permeable bases do not use any stabilizer material. They are more dependent on developing good aggregate interlock for stability.
- Stabilized - Stabilized permeable bases use asphalt or cement stabilizer material as a binder to increase the stability of the aggregate mix. It is pointed out that stabilization is not a substitute for good quality (Durability, soundness) aggregate.

Separator Layer - The separator layer is the silent partner in the design of subsurface drainage systems. Either an aggregate layer or a geotextile can be used.

- Aggregate - An aggregate separator layer must be designed using the filtration equations to retain the smaller size particles. This layer could be included in the structural design of the pavement section.
- Geotextile - The geotextile must have a properly sized opening to retain the smaller size particles, yet open enough to prevent any build up of water.

Edgedrain Location - Edgedrain location is a continuing controversy among pavement engineers. This item will be discussed in more detail in the following section.

Edgedrain installation

- Pre - pave Installation
    - Edgedrain is placed before the main pavement is constructed.
- Postpave Installation
    - Edgedrain is placed after the main pavement has been constructed.

This item will be discussed in more detail in the next section.

- Pre - pave or Post-pave Installation
- Pavement Cross Slope
    - Uniform - Lanes slope to the same shoulder.
    - Crowned - Lanes slope to opposite shoulders

By using a crowned pavement section, the required time to drain can be cut in half. A minimum cross slope of 0.02 ft/ft (2 percent) is recommended.

Shoulder Type

- Similar
  - Concrete pavement with tied concrete shoulder
  - Flexible pavement with flexible shoulder
- Dissimilar - Concrete pavement with flexible shoulder

If the shoulder is constructed of the same material as the main pavement, the resulting pavement-shoulder joint should be much tighter.

The most likely combinations of concrete pavement sections and edgedrain locations are discussed below.

2.2.1 Portland Cement Concrete (PCC) Pavements

2.2.1.1 Vertical Placement of the Permeable Base

The permeable base should be located immediately below the PCC pavement as previously shown in Figure 1-2. This will remove infiltrated water from the pavement section as quickly as possible.

2.2.1.2 Lateral and Vertical Placement of Edgedrains for PCC Pavement

The lateral and vertical placement of edgedrains is an important and vexing problem for engineers. Good arguments can be made for different designs. Designs presented in this project represent the best compromise for the various factors.

For vertical placement of the edgedrain, the top of the edgedrain pipe should be located 50 mm (2 inches) below the bottom of the permeable base so that water can drain out of the permeable base into the edgedrain pipe.

For PCC pavements with asphalt shoulders, the pavement - shoulder joint will open up allowing a relatively large amount of water to enter the pavement section at this point. The edgedrain should be located as close to this joint as feasible as shown in Figure 2-1. This will provide a short, direct path for the water to pass through the permeable base to the edgedrain pipe. Since the edgedrain is located next to the edge of the PCC pavement, time to drain will be kept to a minimum. Also since the edgedrain is located under the paved shoulder, the paving will provide protection for the pipe from heavy wheel loads.

Figure 2-1 shows a widened lane concrete pavement with asphalt concrete shoulders. A uniform cross slope is provided to drain the water over to a roadside ditch. As previously stated, the edgedrain should be located as close to pavement/shoulder joint as feasible. In a pre-pave installation, the edgedrain is placed at the same time the permeable base is constructed; before the PCC pavement is placed. A pre-pave installation is shown in Figure 2-2. The edgedrain is located far enough away from the edge of the concrete pavement so that the paver tracks will run directly on the permeable base - not over the edgedrain pipe. A geotextile is provided under the edge of the permeable base and wrapped around the edgedrain trench to prevent fines from entering.

In a post-pave installation, the edgedrain is constructed after the concrete pavement has been placed. A post-pave installation is shown in Figure 2-3. The edgedrain trench is located far enough away from the pavement slab, so that the slab will not loose support by the permeable base eroding during the trenching operation. The trench should be backfilled with stable, permeable material so there will be no loss of permeability. Again, the edgedrain trench is wrapped with a geotextile to prevent fines from entering.

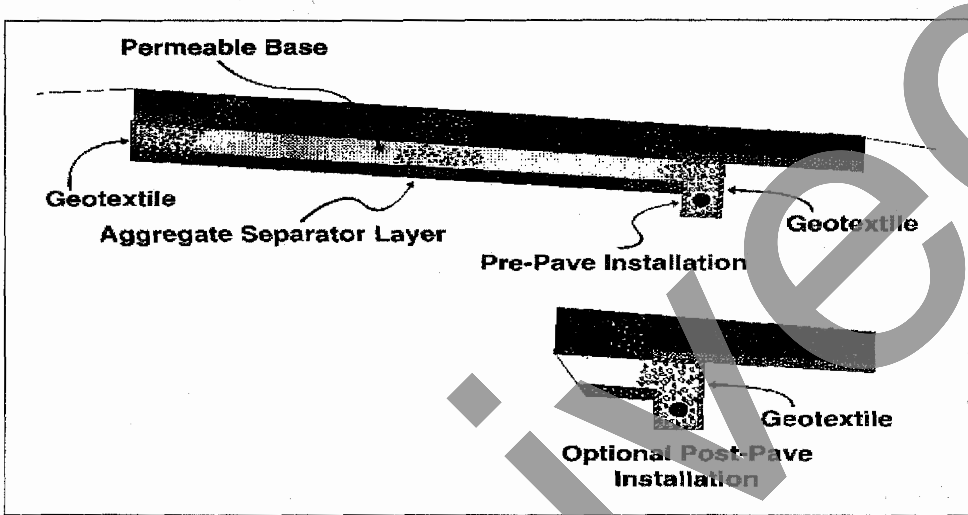

Figure 2 - 1 Edgedrain Location for Concrete Pavement with Asphalt Shoulders

A crowned concrete pavement with tied concrete shoulders is shown in Figure 2-4, since the pavement is crowned, edgedrains must be provided on both sides of the pavement section. The crowned pavement significantly reduces the length of the drainage path thus reducing the time to drain, while the tied shoulders provide considerable support to the pavement edge.

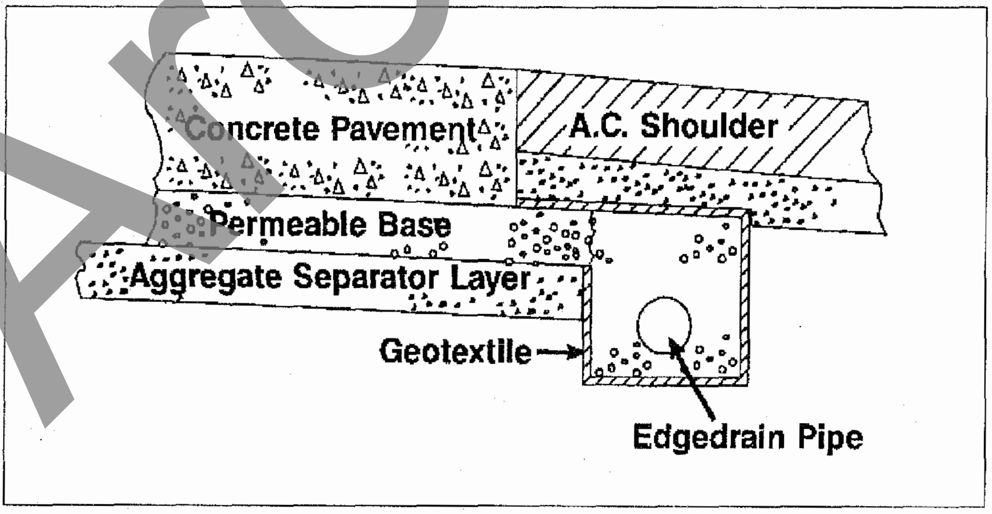

Figure 2 – 2 Pre-pave Edgedrain Installation

For PCC pavements with tied concrete shoulders, the pavement/shoulder joint should be relatively tight allowing less water to enter the pavement section at this point. The edgedrain is moved over closer to the edge of the shoulder so that more of the shoulder can be drained and will still be protected by the paved shoulder as shown in Figure 2.4.

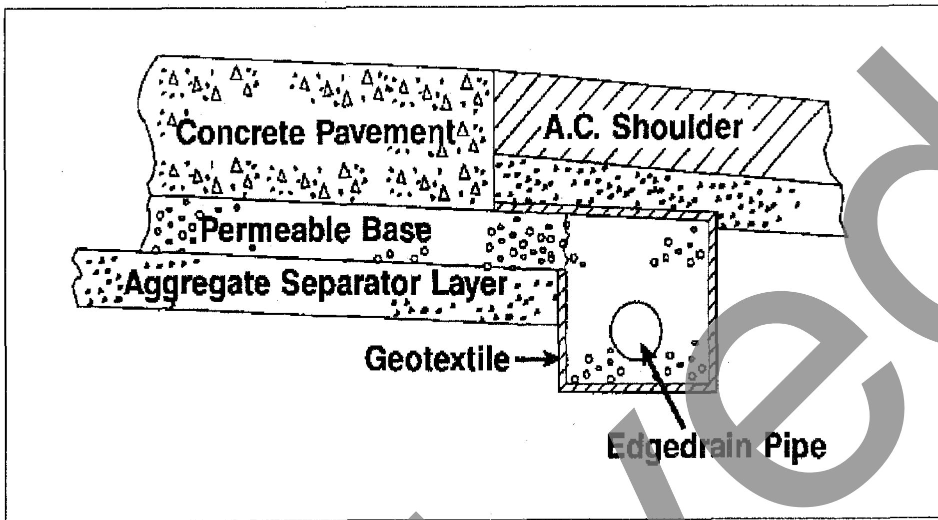

Figure 2 – 3 Post-pave Edgedrain Installation

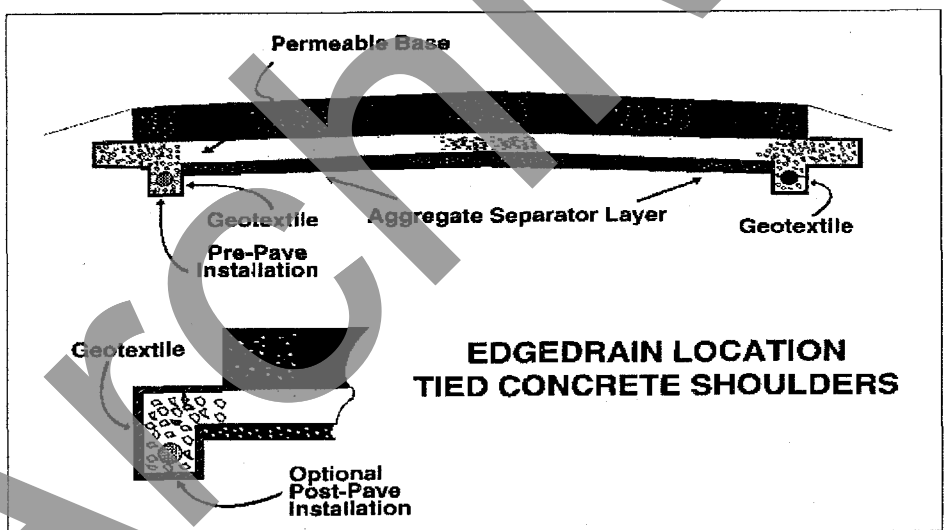

Figure 2 – 4 Edgedrain Location for Crowned Concrete Pavement With Tied Concrete Shoulders

For the pre-pave installation, shown in Figure 2-5, the edgedrain should be located under the shoulder so that it will not be under the paver tracks during the paving operation. **If the edgedrain is located outside of the shoulder, it may not have adequate cover over the edgedrain pipe, depending on the ditch side slope. Also, the paver track may run directly over the edgedrain trench.** Again, a geotextile is provided under the pavement edge and wrapped around the edgedrain trench to prevent fines from entering.

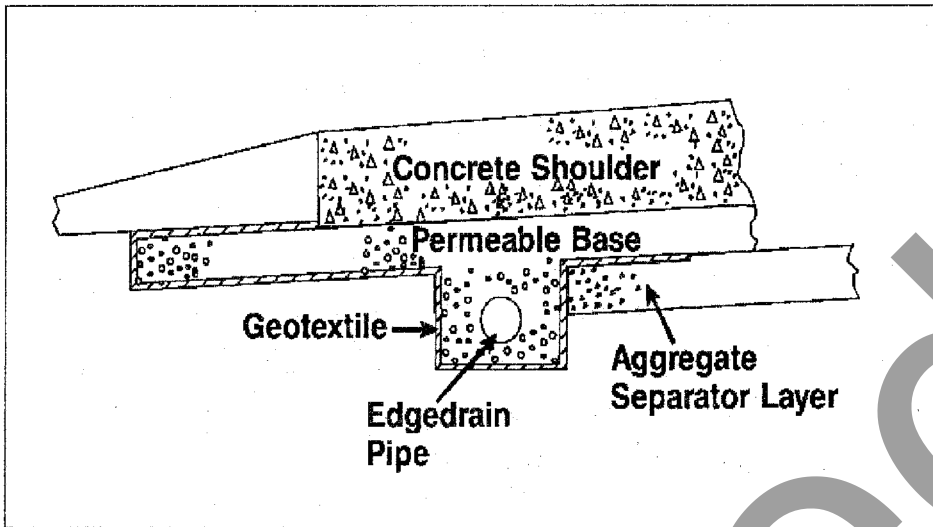

Figure 2–5 Pre-pave Edgedrain Installation for Concrete Shoulders

The post-pave installation is shown in Figure 2-6 (FHWA 1992). Again, the previously stated guidance of locating the trench so that there is no loss of support to the concrete shoulder during the trenching operation still applies. Also previous guidance about geotextile placement and trench backfill still applies.

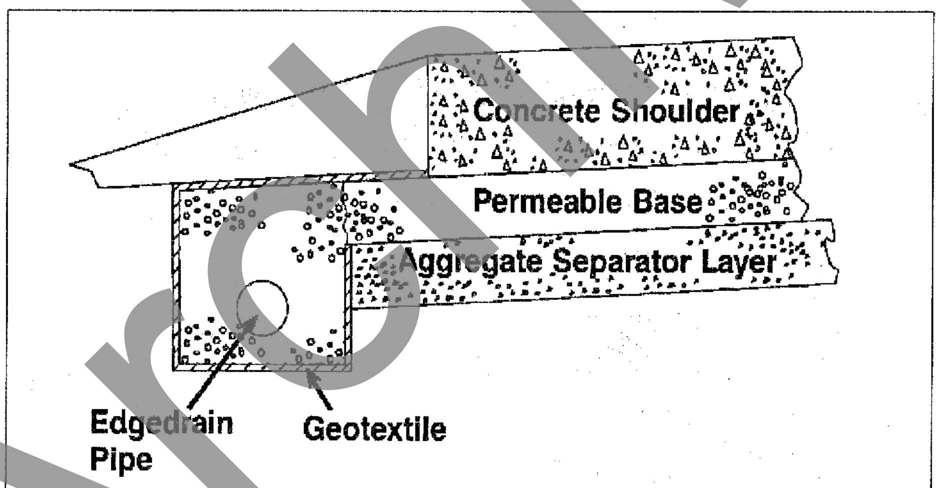

Figure 2-6 Post-pave Edgedrain Installation for Concrete Shoulders.

2.2.2 Asphalt Concrete (flexible) Pavements

2.2.2.1 Vertical Placement of the Permeable Base

The permeable base should be located immediately below the lowest bound layer of the AC pavement as previously shown in Figure 1-4. This will remove infiltrated water from the pavement section as quickly as possible and keep any rising ground water from stripping the bound AC layers.

Any unbound aggregate layers should not be placed on top of the permeable base, since fines and small sand particles will migrate down into the permeable base.

2.2.2.2 <u>Vertical and Lateral Placement of Edgedrains for Flexible Pavements</u>

The design philosophy for the lateral and vertical placement of edgedrains for flexible pavements is quite similar to that stated for PCC pavements. Most likely any flexible pavement would have an asphalt concrete shoulder and asphalt stabilized permeable base as shown in Figure 2-7.

For vertical placement of the edgedrain, the top of the edgedrain pipe should again be located at least 50 mm (2 inches) below the bottom of the permeable base so that water can drain out of the permeable base into the edgedrain pipe. Since drainage of the entire pavement section is more of a goal for flexible pavements, the edgedrain should be located as low as possible. This will be controlled by the invert of the roadside ditch.

For lateral placement of the edgedrain, the edgedrain should be located as close to the main pavement as possible. This arrangement is shown in Figure 2-7. This will provide a minimum time to drain for the permeable base under the main pavement. By locating the edgedrain approximately 30 inches (0.7 meters) from the main pavement, Some drainage of the shoulder will occur. Since the edgedrain is located under the paved shoulder, the paving will provide protection for the pipe from heavy wheel loads.

If the edgedrain is placed before the flexible pavement, in a pre-pave installation, the edgedrain should be moved away from the flexible pavement enough to allow the paver tracks to run on top of the permeable base; not over top of the edgedrain pipe where it might crush the pipe.

If the edgedrain is placed after the main flexible pavement is placed, it is call a post-pave installation. The edgedrain trench should be located far enough away from the main flexible pavement, so that the flexible pavement not loose support by the permeable base eroding during the trenching operation. The trench should be backfilled with stable, permeable material so that there will be no loss of permeability.

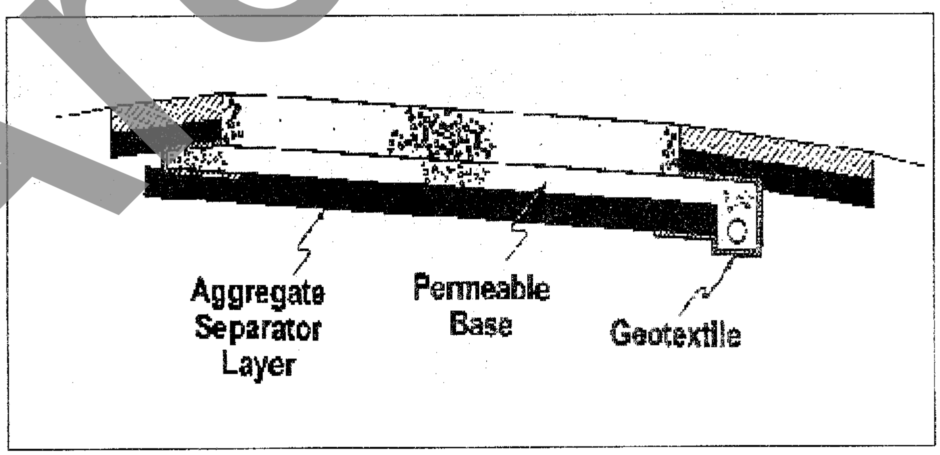

Figure 2-7 Edgedrain Location for Flexible Pavement with Asphalt Shoulders

2.3 Construction Traffic

Construction traffic (concrete delivery trucks) on the completed permeable base course is the single most important parameter in the selection of the type of permeable base to be used. Coordination of construction operations is very important.

2.3.1 PCC Pavements

Since the FHWA recommends the use of load transfer devices (dowel bars), their use should be factored into the design. If dowel baskets are provided, there can be no construction traffic on the completed permeable base; however, if construction traffic is allowed on the completed permeable base, dowel bars should be placed using a dowel bar implanter. During the design stage of a project, a decision should be made concerning allowing construction traffic on the permeable base and method of dowel bar placement.

Unstabilized permeable bases can tolerate some construction traffic on the base, if the coefficient of uniformity is greater than 4. If a large amount of construction traffic is required, the base should be stabilized with asphalt or cement.

Currently, the New Jersey Department of Transportation recommends that no construction traffic be allowed on unstabilized permeable bases. If a Portland cement concrete pavement is to be placed on top of the permeable base, all concrete delivery trucks should deliver the concrete to the paver in a side delivery operation. The width of the concrete paver should be such that the paver completely spans the permeable base with the paver tracks running on the dense graded aggregate base. Side delivery of concrete for the pavement is shown in Photo No. 2.

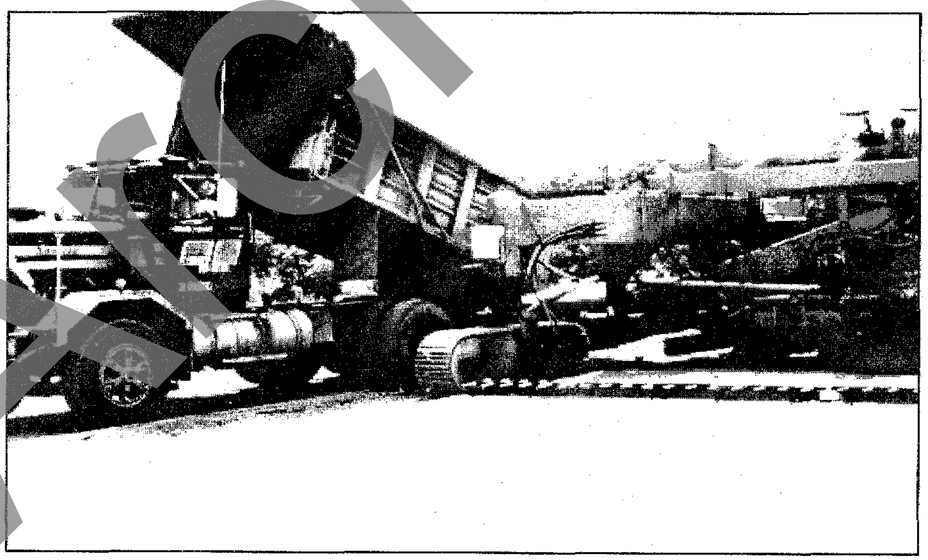

Photo No. 2 Side Delivery of Concrete for the Pavement

2.3.2 <u>Flexible Pavements</u>

If an asphalt concrete pavement is placed on top of the permeable base, only the construction traffic necessary to place the pavement should be allowed on the permeable base.

2.4 <u>Base Material</u>

The aggregate material must have good mechanical interlock; this will require a crushed material. **Both unstabilized and stabilized permeable base material should consist of durable, crushed, angular aggregate with essentially no fines** (minus No. 200 sieve material). The crushed aggregate should have at least two mechanically fractured faces, as determined by the material retained on the No. 4 sieve. Many States require a 90 to 100 percent crushed material with a maximum L. A. Abrasion Wear of 40 to 45 percent.

<u>Durability</u>

The FHWA recommends that only crushed stone be used in permeable bases. The belief is that crushed gravel does not provide enough stability during the construction phase. The aggregate for the permeable base should at least meet the requirements for a Class B Aggregate in accordance with AASHTO M 283-83, **<u>Coarse Aggregate for Highway and Airport Construction.</u>** This means that the L. A. Abrasion Wear should not exceed 45 percent as determined by AASHTO T 96-94, **<u>Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine.</u>**

Since the permeable base is subject to freeze-thaw cycles, the durability of the aggregates should be tested by a soundness test. **The FHWA recommends that the soundness percent loss should not exceed the requirement for a Class B Aggregate as specified in AASHTO M 283-83. This specification requires that the soundness percent loss not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectfully. The tests should be in accordance with AASHTO T 104-97, Soundness of Aggregate by the Use of Sodium Sulfate or Magnesium Sulfate.**

<u>Plasticity</u>

Plasticity is the ability of a soil or aggregate to undergo unrecoverable deformation at constant volume without cracking or crumbling. Plasticity is an indicator of the amount of clay in a soil and the strength of the soil. The New Jersey Department of Transportation requires that the aggregate material be classified as **non-plastic** in accordance with AASHTO T 90-96, **<u>Determining the Plastic Limit and Plasticity Index of Soils.</u>** This requirement applies to both unstabilized and stabilized permeable bases.

Effective Diameter and Coefficient of Uniformity

An examination of the distribution of the particle sizes provides an insight into the stability/permeability interaction of the gradation of an aggregate or soil. The effective diameter (D_{10}) and the coefficient of uniformity (C_U) are two terms developed from the particle distribution that help define this relationship.

The effective diameter (D_{10}) is the particle size at which 10 percent of the material is finer. The larger the effective diameter, the greater the permeability of the material will be.

The coefficient of uniformity (C_U) is the ratio of D_{60}/D_{10} ($C_U = D_{60} / D_{10}$). This parameter represents the spread of the gradation between the 60 and 10 percent passing values. Open graded material will have a low range (2 - 6), while dense graded material will have a range of 20 to 50. A value of 4 is the accepted threshold for unstable gradations. In the Unified Soil Classification System, larger size granular materials with a C_U greater than 4 are classified as well graded. If the coefficient of uniformity is less than 4, problems may occur with compaction of the permeable base. **If the coefficient of uniformity is greater than 4, the permeable base should be able to withstand a moderate amount of construction traffic.**

If the percent passing the No. 200 sieve is greater 12 percent, the C_U should not be used since it is outside of its intended range.

Recommended gradations of the permeable base material vary depending on whether the material is stabilized or unstabilized. Since the in-place coefficient of permeability can vary significantly from the design coefficient of permeability, a **minimum design coefficient of permeability of 1000 feet/day is recommended (FHWA 1992).**

2.5 Unstabilized Permeable Base (PCC Pavements)

The SHA's that use unstabilized permeable bases have developed gradations that represent a careful trade-off of constructability/stability and permeability. Unstabilized materials contain more smaller size aggregate to provide stability through aggregate interlock; however, this results in lower permeability. To provide good stability for paving equipment, **unstabilized aggregate should be composed of 100 percent crushed stone.**

Unstabilized materials generally have a coefficient of permeability on the order of 1000 to 3000 feet per day.

For example, Pennsylvania Department of Transportation recommends that **unstabilized permeable base material should have a coefficient of uniformity greater than 4 to insure stability of the base.**

2.5.1 Unstabilized Permeable Base Gradations

Below is the New Jersey Department of Transportation gradation, Table 2-1, for unstabilized material, which provides satisfactory permeability (greater than 1000 feet per day) and good stability to carry construction equipment. This gradation is plotted on a gradation chart in Figure 2-8.

Table 2-1. New Jersey unstabilized permeable base gradation

Sieve Size (mm)	Alternate Designation	Percent Passing
37.5	1-1/2"	100
25.0	1"	95 - 100
12.5	½"	60 – 80
4.75	No. 4	40 – 55
2.36	No. 8	5 - 25
1.18	No. 16	0 - 8
0.300	No. 50	0 - 5

The New Jersey Department of Transportation requires that the permeable base material be classified as non-plastic in accordance with AASHTO T 90-96, **Determining the Plastic Limit and Plasticity Index of Soils.**

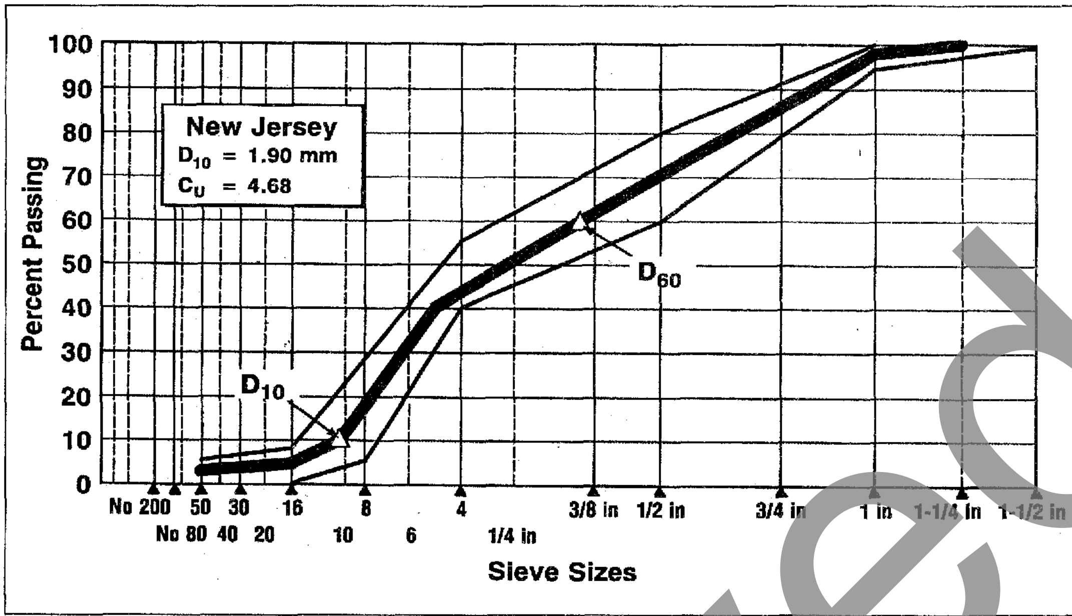

Figure No. 2-8 Plot of New Jersey Gradation

Table 2-2 provides gradations of unstabilized permeable bases being used by SHA's.

Table 2-2 Unstabilized permeable base gradation

Sieve Size	Alternate Designation	Iowa	Minnesota	New Jersey	Wisconsin OGBC No. 1	Wisconsin OGBC No. 2
50.0	2"					
37.5	1-1/2"			100		
25.0	1"	100	100	95 - 100	100	100
19.0	3/4"		65 - 100		90 - 100	
12.5	½"			60 - 80		
9.5	3/8"		35 - 70		20 - 55	45 - 65
4.75	No. 4		20 - 45	40 - 55	0 - 10	15 - 45
2.36	No. 8	10 - 35		5 - 25	0 – 5	
2.0	No. 10		8 - 25			0 - 20
1.18	No. 16			0 - 8		
0.425	No. 40		2 - 10			0 - 10
0.300	No. 50	0 - 15		0 - 5		
.075	No. 200	0 - 6	0 - 3			0 - 5

Note: Wisconsin - gradation is the same as AASHTO No. 67

2.5.2 Placing Unstabilized Permeable Base Material

Unstabilized aggregate will be dumped directly on to the aggregate separator layer. Since this layer is a dense graded base, there should be no rutting or displacement of the aggregate separator layer. A tracked asphalt paver should be used to spread the aggregate material, since rubber tire paver may cause rutting of aggregate separator layer.

To ensure good construction, a string line should be used to control the line and grade. A string line arrangement is shown in Photo No. 3.

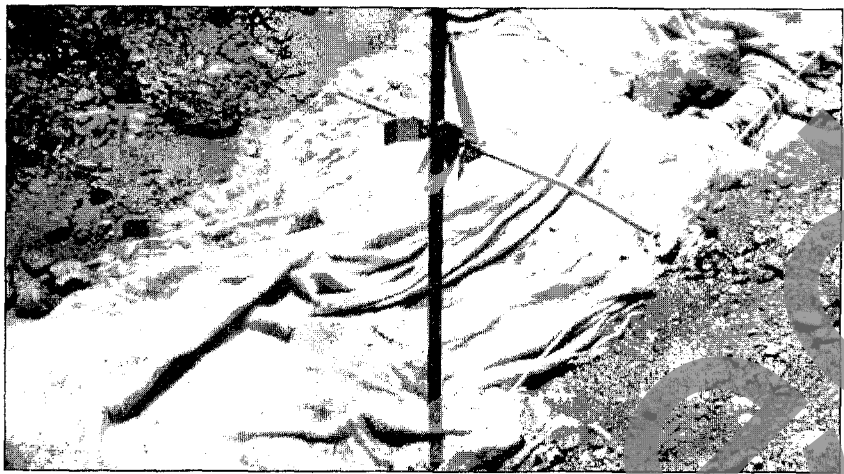

Photo No. 3 String Control for line and Grade

2.5.3 <u>Compaction of Unstabilized Permeable Bases</u>

Compaction of permeable bases has also been recognized as a concern. The conventional approach of requiring a fixed percentage of a maximum density is not applicable.

For permeable bases, maximum density is not achievable since undue crushing of the aggregates will occur destroying the permeability of the base course. The purpose of compacting a permeable base is to seat the aggregate.

For unstabilized permeable bases, most SHA's specify one to three passes of a 4.5 to 9 metric ton (5 to 10 ton) steel-wheeled roller. Vibratory rollers should be used with care. Over rolling can cause degradation, over densification of the material and a subsequent loss of permeability.

An adequate density level should be determined by trial compaction of a control strip. Compaction should continue until no appreciable increase in density occurs without crushing the aggregate. This density level then becomes a standard benchmark level. Compaction of the permeable base roadway must then meet this standard.

A completed unstabilized permeable base is shown in Photo No. 4.

Photo No 4. Completed Unstabilized Permeable Base

Quality control for compaction can be achieved by using the New Jersey Department of Transportation approach as outlined below.

2.5.4 New Jersey Department of Transportation's Approach

Control Strips

One or more control strips shall be constructed at the beginning of work for the purpose of determining the project's compaction requirements. An additional control strip shall be constructed when a change is made in the type or source of aggregate material, whenever a change occurs in the composition of the material from the same source or as directed. Each control strip shall consist of an area of at least 335 m^2 (400 square yards) and shall be constructed of the same material as that specified for the construction of the project.

The control strip shall be compacted by a minimum of two passes of the compaction equipment. Compaction shall continue until no appreciable increase in density is obtained by additional passes without crushing the aggregate. Density of the control strip shall be determined in accordance with the current provisions of AASHTO T 238-97, **Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depths)**, Method A.

Upon completion of compaction, a minimum of ten (10) tests will be made at random locations to determine the average in-place density of the control strip. The average value shall be **Average Reference Maximum Density** for the permeable base material from the same source used elsewhere on the project.

Compaction Acceptance

For purposes of monitoring conformance to the compaction requirements, the non-stabilized, permeable base constructed on the project shall be divided into lots consisting of approximately 4,200 m^2 (5,000 sq. yd.) or less of area.

The engineer shall determine the average lot density of five (5) randomly selected locations in the lot. Densities shall be determined in accordance with the current provisions of AASHTO T 238-97, **Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depths)**, Method A. This average lot density shall not be less than 95% of the **Average Reference Maximum Density** in the control strip. If a lot fails to meet requirement, it shall be recompacted by the contractor at his expense and shall be resubmitted for acceptance. The engineer shall determine the new average lot density. If this density still fails to meet 95% of the Average Reference Maximum Density, each SHA should determine the course of action. A penalty or reconstruction of the permeable base may be required.

2.5.5 Guide Specifications for Construction of Unstabilized Permeable Bases

Guide specifications for the construction of unstabilized permeable bases are provided in Appendix A.

2.6 Stabilized Permeable Base

Stabilized permeable bases utilize open-graded aggregate that has been stabilized with asphalt cement or Portland cement. Stabilizing the permeable base provides a stable working platform without appreciably affecting the permeability of the material. **A primary purpose of the stabilizer is to provide structural strength to the permeable base layer.** This increased strength should prevent premature cracking in PCC pavements. Also, the stabilizer holds the aggregate particles in place preventing long-term consolidation of the permeable base. This will allow the permeable base to maintain its permeability.

The secondary purpose of the stabilizer is to provide stability of the permeable base during the construction phase.

Due to the small amount of stabilizing material used and the nature of the open-graded material (large amount of voids), it is likely that cement treated permeable material will be susceptible to freeze-thaw action and asphalt treated permeable materials will be subject to stripping. It is for this reason we recommend hard, durable, **angular**, crushed aggregates be used for stabilized bases.

2.6.1 Stabilized Permeable Base Gradations

Several SHA's use the AASHTO No. 57 gradation for their stabilized permeable bases. The gradation is provided in Table 2-3.

Some SHA's provide an additional requirement limiting the amount of material passing the No. 200 sieve to 0-2 percent. The purpose of this requirement is to limit the amount of fines.

By limiting the amount of material passing the No.8 or 16 screen, the effective diameter (D_{10}) of the material will be large ensuring high permeability. The coefficient of permeability should be greater than 3,000 feet per day.

Table 2-3 AASHTO No. 57 gradation

Sieve Size (mm)	Alternate Designation	Percent Passing
37.5	1-1/2"	100
25.0	1"	95 - 100
12.5	½"	25 - 60
4.75	No. 4	0 - 10
2.36	No. 8	0 - 5

The AASHTO No. 67 gradation is now being used by several SHA's for their permeable bases. The gradation is provided in Table 2-4 and plotted on a gradation chart in Figure 2-9

Table 2-4 AASHTO No. 67 Gradation

Sieve Size (mm)	Alternate Designation	Percent Passing
25.0	1"	100
19.0	3/4"	90 - 100
9.5	3/8"	20 - 55
4.75	No. 4	0 - 10
2.36	No.8	0 - 5

FHWA recommends that the contractor be provided with an option to select the type of stabilizing material when stabilization is required.

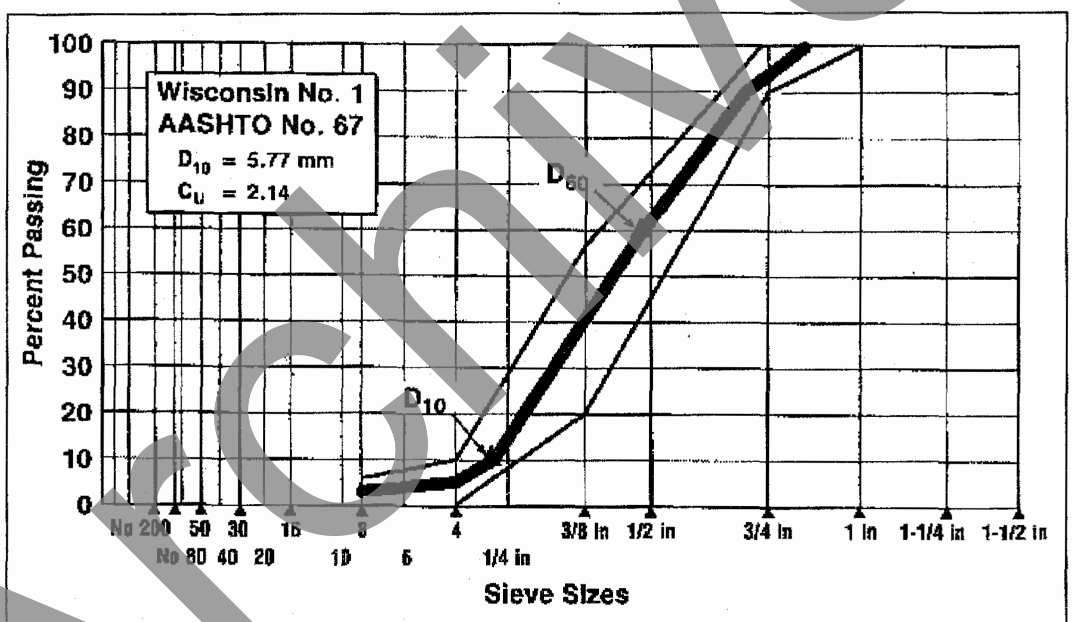

Figure 2-9 Plot of AASHTO No. 67 Gradation.

Note that the slope of the plot is steeper than the New Jersey gradation and that the effective diameter (D_{10}) plots farther to the right. Both of these observations indicate that the gradation should have more permeability and less stability.

2.6.2 Asphalt Stabilized Permeable Bases

2.6.2.1 Asphalt Material

The stabilization material predominately used is asphalt cement. As previously stated there are two purposes in applying stabilization. The first is to increase the strength of the pavement section so that good pavement performance will be achieved. The second purpose is to provide strength to the aggregate mix so that the permeable base material will have enough strength to get through the construction phase.

In the past a stiffer grade of asphalt, AC 40 or AR 8000, was suggested (Demo87, Participant Notebook). Since then, a new asphalt grading system, **AASHTO MP1-98, "Performance Graded,"** has been developed for the Superpave design procedure. This system requires more detailed analysis by the pavement engineer before a grade of asphalt can be specified. In the new system, the required grade of the asphalt is given in the following format:

PG XX – YY

Where:

PG = Performance Graded
XX = 7 day Average Maximum Temperature (+ ^{0} C)
YY = 7 day Average Minimum Temperature (- ^{0} C)

The first number **(XX)** is the 7 day Average Maximum pavement temperature **(plus XX^0 C)** for a selected project geographical location. This value represents the hot weather temperature that the pavement must resist. This approach protects the pavement against permanent deformation (rutting). The second number **(YY)** is the 7 day Average Minimum pavement temperature **(minus YY^0 C)**. This temperature attempts to protect the pavement against low temperature cracking.

These temperatures are weather station temperature values determined by Superpave Data Bind software or are available in **SHRP Report 648A, "Weather Database for the Superpave Mix Design System."**

For example, say a **PG 58 – 22** asphalt grade has been specified. This means that the hot weather temperature is **58^0 C (136^0 F)** while the cold weather temperature is – **22^0 C (-7^0 F).**

FHWA recommends that the asphalt grade be determined by a pavement engineer using Superpave software. FHWA also suggests the following asphalt grades for a major portion of the United States:

PG 76 – 22 or PG 76 – 16

Since the asphalt stabilized permeable base will be covered by the pavement, it should not be subjected to a colder environment. Perhaps a lower (warmer) cold weather temperature **($-YY^0$ C)** could be specified.

Asphalt Content

FHWA recommends an asphalt content of 3 percent by weight. This amount of asphalt is necessary to give the mix the necessary strength.

Anti-Stripping Agent

Stripping of the permeable base aggregate has been identified as a serious problem. The use of a heat-stable anti-stripping agent is strongly recommended to keep stripping to a minimum.

Pre Heated Aggregates

The California Department of Transportation (CALTRANS) recommends that when the stiffer asphalt cement (AR 8000) is used the aggregate should be heated to between 135 to 165 degrees C. (275 - 325 degrees F.) to prepare the aggregate so that the aggregates and asphalt cement are blended into a homogenous mix.

2.6.2.2 Asphalt Stabilized Permeable Base Gradations for PCC Pavements

Table 2-5 provides asphalt stabilized permeable base gradations being used by SHA's (FHWA 1992).

Table 2-5 Asphalt stabilized permeable base gradations

Sieve Size (mm)	Alternate Designation	California	North Carolina	Wisconsin	Wyoming
37.5	1-1/2"		100		100
25.0	1"	100	95 - 100	100	95 – 100
19.0	3/4"	90 - 100		90 – 100	
12.5	½"	35 - 65	25 - 60		25 – 60
9.5	3/8"	20 - 45		20 – 55	
4.75	No. 4	0 - 10	0 - 10	0 – 10	0 – 10
2.36	No. 8	0 - 5	0 - 5	0 – 5	0 – 5
0.075	No. 200	0 - 2	0 - 3		

Note: California - 2-1/2% asphalt content, AR-8000 grade
North Carolina - AASHTO No. 57 gradation plus 0-3 % passing No. 200 sieve
Wisconsin - AASHTO No. 67 gradation, > 1-1/2 % asphalt content
Wyoming - AASHTO No. 57 gradation, 2-1/2 % asphalt content, AC 20

2.6.2.3 Asphalt Stabilized Permeable Base Gradations for Flexible Pavements

Most likely the only type of permeable bases used with a flexible pavement would be an asphalt stabilized base. In flexible pavement, stability (strength) is much more of a consideration. A New Jersey gradation used in flexible pavement is given in Table 2-6 and plotted in Figure 2-10.

Table 2-6 New Jersey Bituminous Stabilized Open Graded (BSOG) Gradation

Sieve Size (mm)	Alternate Designation	Percent Passing
25.0	1"	100
19.0	3/4"	95 – 100
12.5	½"	85 – 100
9.5	3/8"	60 – 90
4.75	No. 4	15 – 25
2.36	No. 8	2 – 10
0.075	No. 200	0 – 5

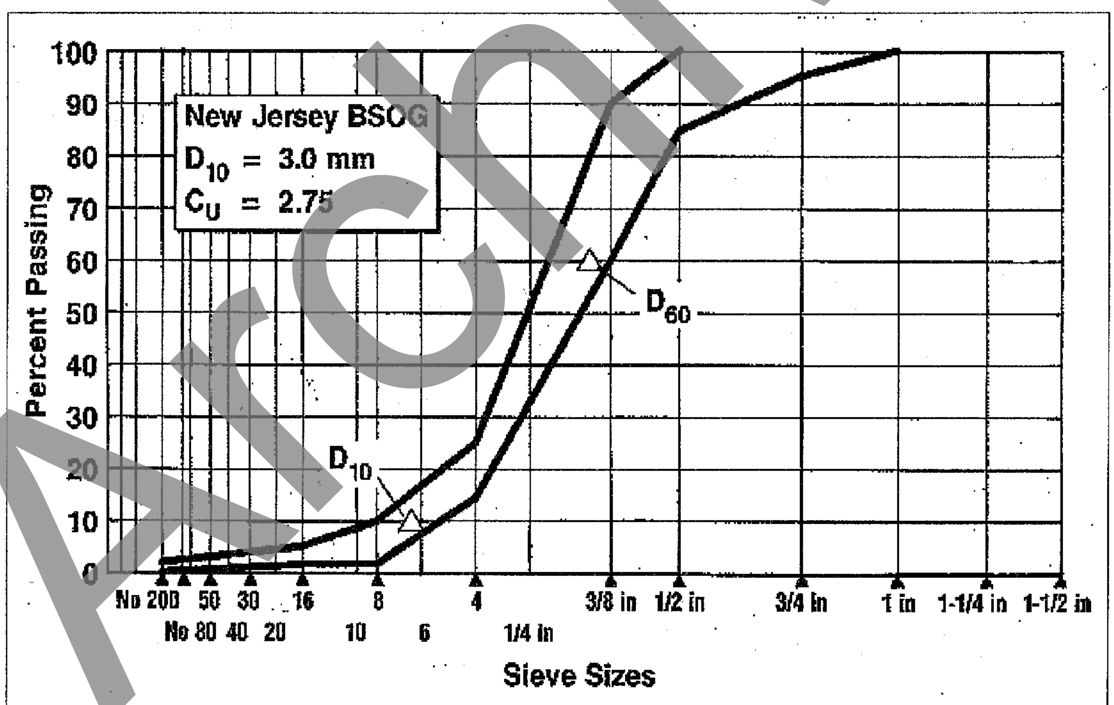

Figure 2-10 Plot of New Jersey Bituminous Stabilized Open Graded Gradation

It is interesting to compare the New Jersey BSOG with the New Jersey Non-stabilized and the AASHTO No. 67. A comparison of the effective diameter (D_{10}) and Coefficient of Uniformity (C_U) for these gradations is given in Table 2-7.

For comparison purposes, these three gradations are plotted in Figure 2-11. From this figure, it can be seen that the New Jersey BSOG gradation falls between the other gradations. From Table 2-7 and Figure 2-11, it is anticipated that the New Jersey BSOG gradation would have a permeability greater than the New Jersey Non-stabilized, but less than the AASHTO No. 67. It is also anticipated that the New Jersey BSOG would have more stability than the New Jersey Non-stabilized since it is asphalt stabilized. Also it is likely that the New Jersey BSOG would have more stability than an asphalt stabilized AASHTO No. 67 since the gradation falls to the left of the AASHTO No. 67 and has a Coefficient of Uniformity that is slightly greater than AASHTO No. 67.

Table 2-7 Comparison of Gradations

Gradation	Effective Diameter (D_{10})	Coefficient of Uniformity (C_U)
New Jersey Non-stabilized	1.90 mm	4.68
New Jersey BSOG	2.99 mm	2.75
AASHTO No. 67	5.77 mm	2.14

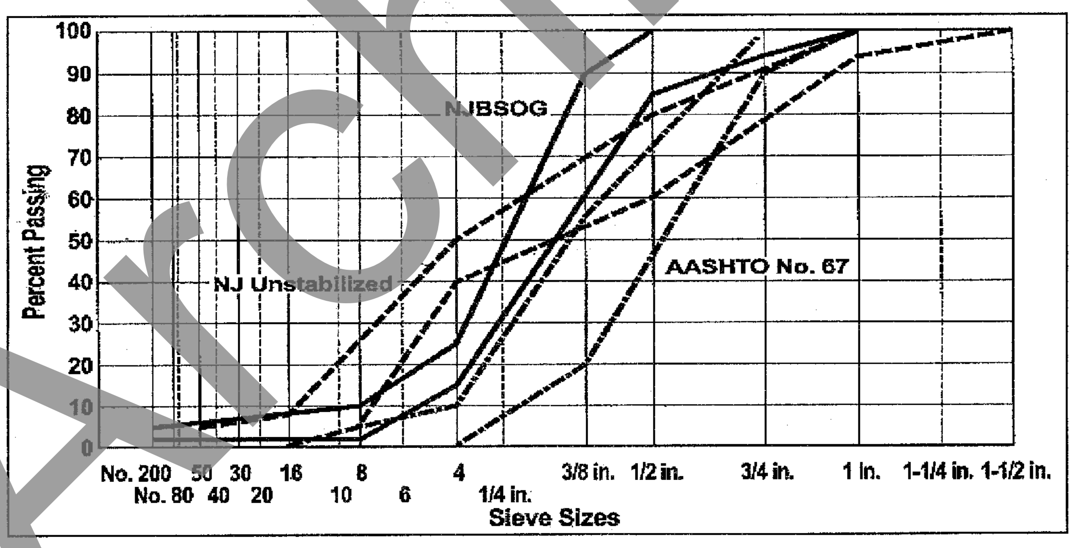

Figure 2-11 Comparison of Gradations

2.6.2.4 <u>Placing Asphalt Stabilized Permeable Base Material</u>

Guidance for placing the asphalt stabilized permeable base is essentially the same as that given for unstabilized aggregate permeable base. Again a tracked asphalt paver should be used to spread the asphalt stabilized mix, since a rubber tire paver may cause rutting of aggregate separator layer.

2.6.2.5 <u>Compaction of Asphalt Stabilized Permeable Bases</u>

For asphalt stabilized permeable bases, most SHA's specify one to three passes of a 4.5 to 9 metric ton (5 to 10 ton) steel-wheeled roller. Vibratory rollers may be used in the static mode to compact asphalt stabilized permeable bases, Over rolling can cause degradation of the material, over densification, and a subsequent loss of permeability.

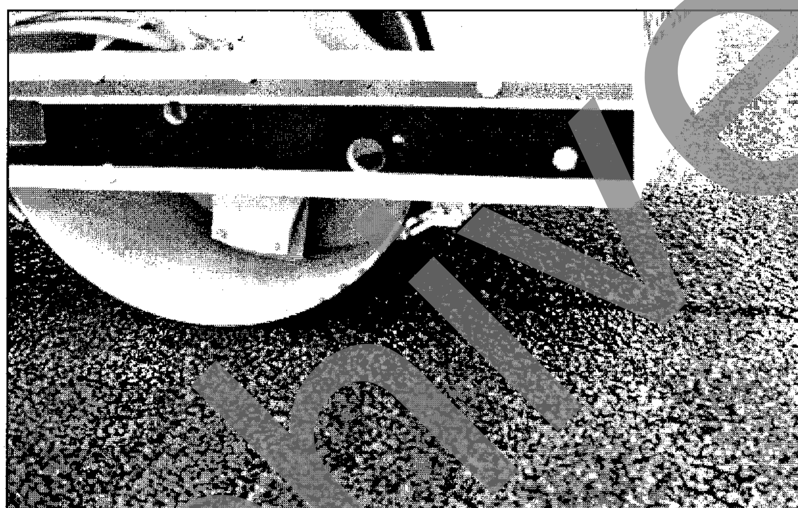

Photo No. 5 Rolling Asphalt Stabilized permeable bases.

CALTRANS requires that asphalt stabilized permeable bases be spread at a temperature between 93-120 degrees C. (200-250 degrees F.) as measured in the hopper of the paving machine. One recommended alternate for compaction is one complete coverage of the base course with a steel-wheeled, 2-axle tandem roller weighing between 8 and 12 tons. Compaction should begin when the temperature of the permeable base has cooled to 65 degrees C. (150 degrees F.) and should be completed before the temperature falls below 38 degrees C. (100 degrees F.).

The New Jersey Department of Transportation uses the same approach to compaction of asphalt stabilized permeable bases as the one described in the unstabilized section. Vibratory rollers may be used in the static mode.

Construction traffic should not be allowed on the completed base during the next 24 hours.

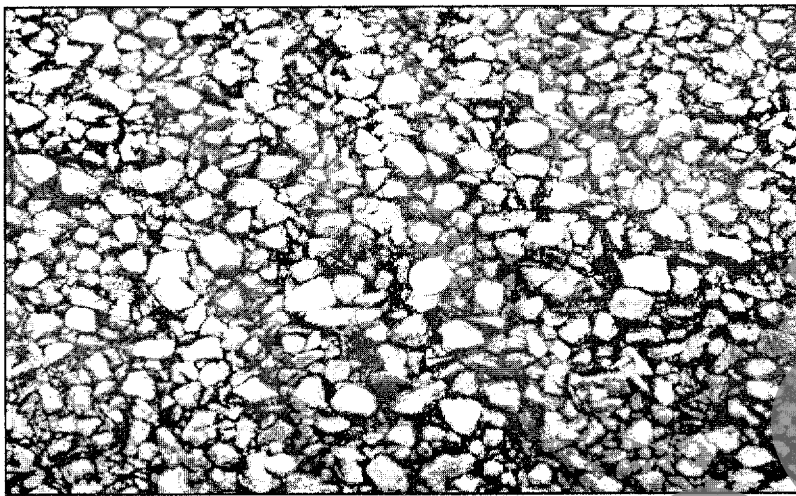

Photo No. 6 Completed Asphalt Stabilized Permeable Base.

The completed asphalt stabilized permeable base is shown in Photo No. 6. Note the void space in the material. It is this network of voids that provides permeability to the mix.

2.6.2.6 Guide Specifications for Construction of Asphalt Stabilized Bases

Guide specifications for the construction of asphalt stabilized permeable bases are provided in Appendix B.

2.6.3 Cement Stabilized Permeable Bases for PCC Pavements

2.6.3.1 <u>Cement Material</u>

Portland cement has also been used as a stabilization material. **An application rate of 112 to 167 kg/m^3 (2 to 3 bags per cubic yard) is recommended.** Cement should be Type I, Type I-p or Type II conforming to the appropriate sections of the SHA's standard specifications or ASTM C 150-97, **<u>Portland Cement.</u>**

This base material has considerable initial strength; however, the high strength may not be permanent due to possible leaching of the cement or breakdown of the concrete due to freeze-thaw action.

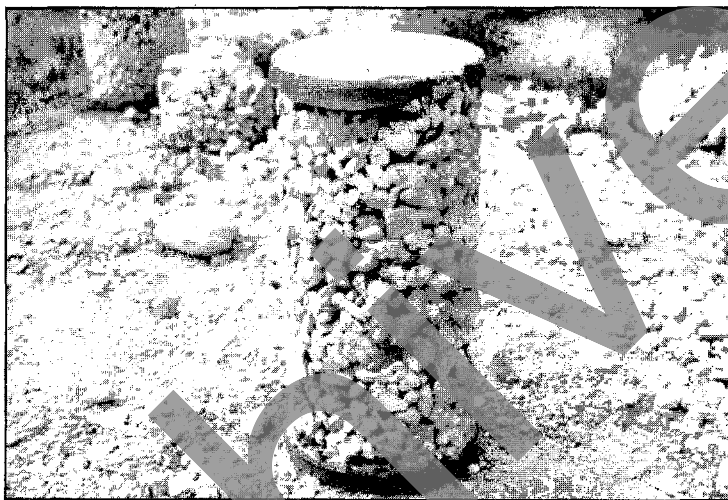

Photo No. 7 Cement Stabilized Permeable Base Test Cylinder

Photo No. 7 shows a cement stabilized permeable base test cylinder. This photo demonstrates two important features of cement stabilized materials. The honey-comb nature of the mixture provides a network of voids that provide the mixture with its permeability. Second, the strength of the material is demonstrated by the fact that the material is free standing after removing the outer shell of the test cylinder.

2.6.3.2 Cement Stabilized Permeable Base Gradations

Table 2-8 provides cement stabilized permeable base gradations being used by SHA's.

Table 2-8 Cement stabilized permeable base gradations

Sieve Size (mm)	Alternate Designation	California	Virginia	Wisconsin
37.5	1-1/2"	100		
25.0	1"	88 – 100	100	100
19.0	3/4"	x $\pm$ 15		90 - 100
12.5	½"		25 – 60	
9.5	3/8"	x $\pm$ 15		20 - 55
4.75	No. 4	0 – 16	0 – 10	0 - 10
2.36	No. 8	0 – 6	0 – 5	0 - 5

Note: California - 282 lbs, water/cement ratio approximately 0.37,
"X" percentage submitted by the Contractor
Virginia - Slightly Modified AASHTO No. 57 Gradation, 225 lbs of cement
Wisconsin - AASHTO No. 67 Gradation, 200 lbs of cement

2.6.3.3 Placing Cement Stabilized Permeable Base Material

The cement stabilized mixture will be quite harsh and stiff; therefore a concrete paver should be used to spread the mix.

2.6.3.4 Consolidation

For compacting cement stabilized permeable bases, a number of SHA's have had good success in using only vibrating screeds and plates. Again, the purpose of the stabilizer material is to set up the permeable base for the concrete paving operation.

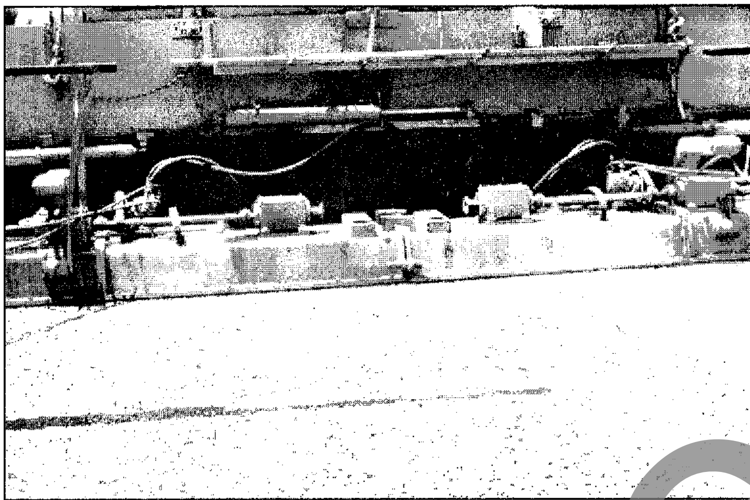

Photo No. 8. Compacting Cement Stabilized Permeable Base Material

Placing cement stabilized permeable material is shown in Photo No. 8. Vibrating Screeds behind the paver provides adequate consolidation of the permeable base material.

Quality control for consolidation can be achieved by using the Virginia Dept. of Transportation approach as outlined below.

2.6.3.5 Virginia Dept. of Transportation Approach

Approved concrete pavers with vibrating screeds or plate vibrators should be used to place and consolidate the cement stabilized material. Screed or plate vibrators should be used to consolidate the material to a consistent finish across the width of the course. The material should not be compacted to the point that it is not free draining or that the aggregate is crushed.

Control Strips

One or more control strips should be constructed at the beginning of work for the purpose of determining the project's compaction requirements. An additional control strip should be constructed when a change is made in the type or source of aggregate material, whenever a change occurs in the composition of the material from the same source or as directed.

Each control strip should consist of an area of at least 335 m^2 (400 square yards) and should be constructed of the same material and thickness as that specified for the construction of the project.

Upon completion of the control section, a minimum of four (4) test for minimum cement content should be taken. The mean result of four (4) tests shall be within $\pm$ 17.80 kg/m^3 (30 lbs. per yd^3) of the minimum cement content.

Consolidation Acceptance

Acceptance of aggregate coating in cement stabilized permeable base material will be based on the mean results of tests for the minimum cement content performed on samples taken in a stratified random manner from each lot. The rate of sampling will be four (4) per lot. A lot measurement is defined as 2,000 metric tons of material.

A lot will be considered to be acceptable if the mean result of four (4) tests is within $\pm$ 17.80 kg/m^3 (30 lbs. per yd^3) of the minimum cement content. If an individual test result indicates that the cement content of the material is deficient by more than 21 kg/m^3 (35 lbs. per yd^3) from the design cement content, that portion of the material represented by the sample will be considered a separate part of the lot and may be removed from the roadway at the discretion of the Engineer.

If the value of the test falls below the minimum cement content, a payment adjustment will be applied to the contract unit price.

2.6.3.6 Curing

Curing is an important aspect of constructing cement stabilized bases. One method is to cover the permeable base with polyethylene sheeting for 3 to 5 days. Another method is to apply a fine water mist cure to the cement stabilized base several times on the day after the base is placed. The Oklahoma Department of Transportation recommends that a fine mist spray be applied to the cement stabilized base every 2 hours for a period of 8 hours starting the next day after placing the base. The surface of the cement stabilized permeable base is sprayed with an asphalt emulsion. This serves as a marker to identify the thickness of the concrete pavement when cores are taken.

Curing can also be accomplished by the use of curing compounds. VDOT recommends a white pigmented wax base concrete curing compound meeting the requirements of ASTM C-309-94, **Liquid Membrane-Forming Compound for Curing Concrete** applied at a rate of one liter per 3.68 sq. meters (1 gal per 16.5 yd^2).

A SHA may want to construct a test strip of the base course to determine which curing method to employ, as well as which method of compaction should be used.

2.6.3.7 Guide Specifications for Construction of Cement Stabilized Permeable Bases

Guide specifications for the construction of cement stabilized permeable bases are provided in Appendix C.

2.7 Control Strip

The FHWA recommends that a control strip be constructed at the beginning of construction so the combination of aggregate materials and construction practices be tested, and if necessary, adjusted to produce a stable permeable base. The test section should be constructed using the same aggregate materials and compaction practices that will be used on the project. A minimum length of 152 m (500 ft) is recommended for the test section. The test section should become part of the finished roadway.

2.8 Base Thickness

A minimum thickness of 100 mm (4 inches) is suggested for the permeable base. This thickness should be adequate to overcome any construction variances and provide an adequate hydraulic conduit to transmit the water to the edgedrain.

3.0 SEPARATOR LAYER

3.1 General

A separator layer must be provided between the permeable base and the subbase/subgrade to keep subgrade soil particles from contaminating the permeable base. A separator layer over stabilized subbases/subgrades may not be needed provided the stabilized material is not subject to saturation or high pressures for an extended period of time. An asphalt prime coat placed on the stabilized subbase/subgrade would provide additional protection. **A separator layer can be provided by an aggregate separator layer or geotextile.** FHWA recommends the use of an aggregate separator layer due to its ability to spread vertical loads over a wide area of the subgrade.

Use of geotextiles as a separator layer is covered in detail in **the NHI Course No. 13213, "Geosynthetic Design and Construction Guidelines,"** (Participant Notebook, FHWA HI-95-038 (Revised 1998)), and will not be covered in this text.

It is pointed out that a separator layer is not a substitute for a strong subgrade.

3.2 Design Procedures

The aggregate separator layer must perform several very important functions:

- First, the aggregate separator layer must be strong enough to provide a stable working platform for constructing the permeable base. The aggregate separator layer should not experience any rutting or movement during the paving operation. Since most SHA's use a DGAB for the aggregate separator layer, this material should be strong enough to support the paving operation.

- Second, the gradation of the aggregate separator layer must be carefully selected to prevent fines from pumping up from the subgrade into the permeable base. Basic aggregate filtration equations are used to size the gradation of the aggregate separator to prevent contamination of the permeable base.

- Third, the aggregate separator layer should have a low permeability; the layer should act as a shield to deflect infiltrated water over to the edgedrain.

The dynamic effects of wheel loads must also be considered.

The aggregate separator layer is designed based on the principle that spherical particle will be retained until the diameter of the retaining spheres is 6.46 times greater than the sphere to be retained. This relationship is shown in Figure 3-1 (FHWA 1992). **By limiting the D_{15} size of the aggregate separator layer to less than 5 times the D_{85} size of the subgrade, the larger soil particles of the subgrade will be retained allowing the soil bridging action to start.** Both the aggregate separator layer/subgrade and the permeable base/aggregate separator layer interface must be investigated.

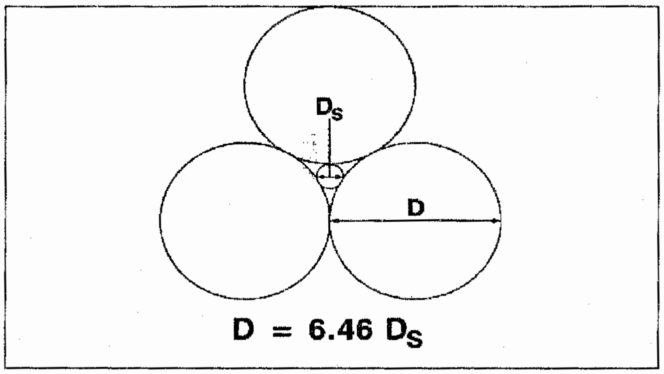

Figure 3-1 Retention of Spheres Relationship

3.3 Aggregate Separator Layer Gradation

Most SHA's like to use a basic, dense graded aggregate base as an aggregate separator layer. Below is a gradation in Table 3-1 used by the New Jersey Dept. of Transportation:

Table 3-1 New Jersey dense graded aggregate base gradation

Sieve Designation (mm)	Alternative Designation	Percent Passing
37.5	1-1/2"	100
19.0	3/4"	55 - 90
4.75	No. 4	25 - 60
0.300	No. 50	5 - 25
0.075	No. 200	3 - 12

This gradation is plotted in Figure 3-2 and the resulting effective diameter (D_{10}) and Coefficient of Uniformity (C_U) are 0.24 mm and 46.77, respectively.

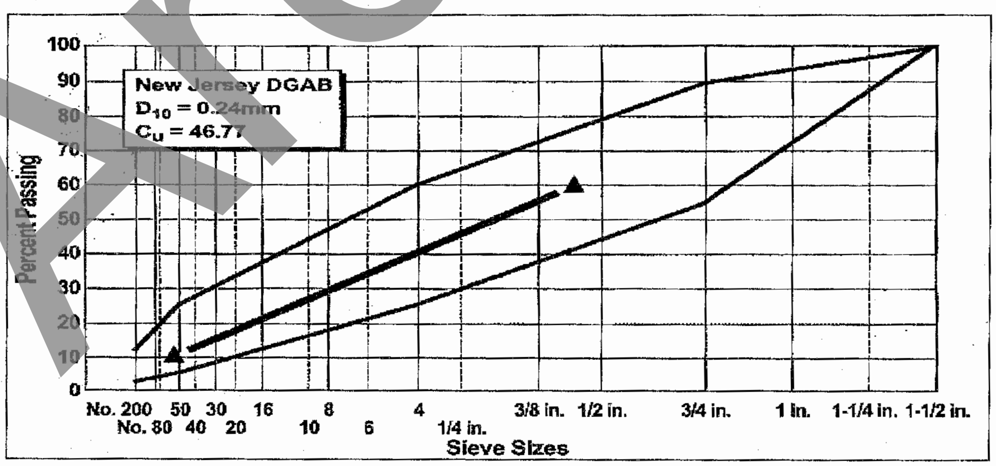

Figure 3-2 Plot of New Jersey DGAB

3.4 Materials

The aggregate separator layer should consist of durable, crushed, angular aggregate material. Aggregate material should have good mechanical interlock. The aggregate for the separator layer should at least meet the requirements for a Class C Aggregate in accordance with AASHTO M 283-83 **Coarse Aggregate for Highway & Airport Construction.** This means that the L.A. Abrasion Wear should not exceed 50 percent as determined by AASHTO T 96-87. FHWA recommends that the soundness percent loss should not exceed the requirements for a Class C Aggregate as specified in AASHTO M 283-83. This specification requires that the soundness percent loss should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectfully, in AASHTO T 104-86.

The New Jersey Department of Transportation requires that the material be classified as non-plastic in accordance with AASHTO T 90-96, **Determining the Plastic Limit and Plasticity Index of Soils.**

3.5 Compaction

The maximum density of the aggregate separator material should be determined in a laboratory by AASHTO T 99-97, **Moisture Density Relationship Using a 5-lb (2.5 kg) Hammer and an 12-in (305 mm) Drop, Method D**, or AASHTO T 180-97, **Moisture Density Relationship Using a 10-lb (4.54 kg) Hammer and an 18-in (457 mm) Drop, Method D**.

Compaction of the aggregate separator layer shall continue until the material complies with the compaction acceptance criteria listed below. The in-place density of the aggregate separator layer shall be determined in accordance with AASHTO T 191-93, **Density of Soil in Place by the Sand Cone Method**, AASHTO T 205-86, **Density of Soil In-Place by the Rubber Balloon Method**, or AASHTO T 238-97, **Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depths)**, Method B and except that only one method will be used through out the project. Moisture content is determined by AASHTO T 239-97, **Moisture Content of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depth)**

Water shall be applied uniformly over the materials during compaction in the amount necessary to obtain the required density.

3.5.1 Control Strips

One or more control strips should be constructed at the beginning of work for the purpose of determining the project's compaction requirements. An additional control strip should be constructed when a change is made in the type or source of aggregate material, whenever a change occurs in the composition of the material from the same source or as directed. Each control strip should consist of an area of at least 335 m^2 (400 square yards) and shall be constructed of the same material as that specified for the construction of the project. The control strip should be compacted by a minimum of two passes of the compaction equipment. Compaction should continue until, no appreciable increase in density is obtained by additional passes.

Upon completion of compaction, a minimum of ten (10) tests will be made at random locations to determine the average in-place density of the control strip. In-place density of the control strip should be determined in accordance with the current provisions of one of the AASHTO tests listed above (AASHTO T 191-93, T 205-86, or T 238-97). If the average density of the material in the control strip is equal to or greater than 95 percent of the aggregate materials maximum density, then the value of the average shall be the Average Reference Maximum Density for the aggregate separator layer. If the control strip does not meet this density, the compaction equipment and or its method of use shall be rejected.

3.5.2 Compaction Acceptance

For purposes of monitoring conformance to the compaction requirements, the aggregate separator layer constructed on the project shall be divided into lots consisting of approximately 4,200 m^2 (5,000 sq. yd.) or less of area.

The engineer shall determine the average lot density of five (5) randomly selected locations in the lot. This average lot density shall not be less than 95% of the **Average Reference Maximum Density** in the control strip taken in accordance with the current provisions of one of the AASHTO tests listed above (AASHTO T 191-93, T 205-86, or T 238-97). If a lot fails to meet requirement, it shall be re-compacted by the contractor at his expense and shall be resubmitted for acceptance.

3.6 Layer Thickness

A minimum thickness of 100 mm (4 inches) is recommended for the aggregate separator layer based on construction considerations.

3.7 Construction Considerations

The aggregate separator layer is equally important as the permeable base and subgrade in developing a strong pavement section. Again, quality of aggregates and proper compaction are the keys to a strong separator layer. This layer is necessary to provide a stable platform for placing the permeable base and concrete pavement.

3.8 Guide Specifications for Construction of Dense Graded Aggregate Bases

Guide specifications for the construction of an aggregate separator layer are provided in Appendix D.

4.0 LONGITUDINAL EDGEDRAINS

4.1 General

Longitudinal edgedrains are a key element in drainable pavement systems. It is imperative that the edgedrain has the necessary hydraulic capacity to handle the water being discharged from the permeable base. Each element of the drainage system should increase in capacity, as the water, moves towards the outlet so that there are no weak links in the system. Since a permeable base is used, all runoff that enters the pavement section should drain quickly to the edgedrain.

There are three basic types of edgedrains:

- Aggregate trench
- Conventional pipe
- Geocomposite fin drains

Aggregate trench edgedrains are not recommended for the following reasons:

- Low hydraulic capacity
- Inability to be cleaned

Aggregate trench edgedrains will not be covered in this manual.

Generally, geocomposite fin drains are not recommended for use with permeable bases due to their low hydraulic capacity and the inability to be maintained; unless the specific geocomposite has the necessary hydraulic capacity and can be cleaned and inspected. Geocomposite fin drains may be used in some retrofit cases where the anticipated flow rate is low.

The trench backfill and edgedrain pipe must have the necessary capacity to handle the design flows. Erosion of fines should not be a problem since the base should contain very little erodible fine material. The trench backfill material should be stable with the same permeability as the permeable base course to insure capacity. The geotextile used to wrap the edgedrain trench should not extend up into the permeable base to form a barrier.

Underdrains

Engineers use the terms "edgedrain" and "underdrain" interchangeably. Definitions can vary from engineer to engineer. For the purposes of manual, the definition of "underdrain" is any subsurface drainage pipe that is not a longitudinal edgedrain or an outlet pipe.

Problem Slopes

There are several special locations where the slope under the pavement may be quite flat:

- Sag vertical curve
- Horizontal curve transitions
- Level roadway

At the bottom of sag vertical curves, the longitudinal slope will be equal to zero (S = 0.0%). This means that the drainage will be dependent on the cross slope of the roadway. For horizontal curves, as the cross slope transitions from a normal section to a superelevated section, at some point the cross slope will be equal to zero (S_x = 0.0%), while for level roadway the longitudinal **slope is equal to zero (S = 0.0%) which again means that the drainage will be dependent on the cross slope of the roadway**

Both of these areas are potential drainage problem areas. Many engineers will want to place an underdrain at these locations to drain the surrounding area. Unfortunately, the discontinuity in subgrade support caused by the underdrain may more than offset the benefits of drainage.

Engineers now recognize that the transition areas from cut to fill sections represent a potential drainage problem area. Considerable subsurface water can build up in the roadway section. Underdrains may be required to remove this water.

While the design, construction and maintenance of underdrains is outside the scope of this paper, these items would be quite similar to the edgedrain case.

4.2 Edgedrain Location

For permeable bases (new or reconstructed cases), the edgedrain location has been discussed in detail in Section 2.0 Permeable Bases. Edgedrain location and geotextile placement are closely tied in to pre-pave or post pave installation of the edgedrain. In reality, edgedrain location, pre- or post installation, and geotextile placement is one decision.

4.3 Pipe Edgedrains

Conventional pipe edgedrains are recommended because of their relatively high flow capacity and their ability to be maintained. Pipes must have enough strength to resist the loads placed on them.

4.3.1 Pipe Material

There are many different plastic materials used in the manufacture of plastic pipe. Most SHA's use flexible, corrugated polyethylene (CPE) or smooth, rigid, polyvinyl chloride (PVC) pipe. Pipe should conform to the appropriate State or AASHTO specification. It is pointed out that selection of pipe material is strictly a "Buyer Beware" scenario. Engineers must determine if the pipe is adequate for its intended role. Only CPE and PVC pipe will be discussed in this manual.

4.3.1.1 Corrugated Polyethylene

For CPE pipe, AASHTO Specification M 252, Corrugated Polyethylene Drainage Pipe is suggested. "Standard" grade pipe should have a minimum pipe stiffness of 35 psi; however, manufacturers can produce "Landfill Grade" pipe which will have a stiffness of 70 psi.

4.3.1.2 Poly (Vinyl) Chloride

Table 4-1 contains the specification number and specification title for different PVC pipes. These specifications provide a large range of pipe stiffness.

Table 4-1 Summary of PVC Pipe Specifications

Specification Number	Specification Title	Pipe Classification
AASHTO M 278	Class PS46 Polyvinyl Chloride (PVC) Pipe	PS 46
ASTM D 3034	Type PSM Poly (Vinyl) Chloride (PVC) Pipe and Fittings Based on Controlled Inside Diameter	SDR 35
		SDR 26
		SDR 23.5
AASHTO M 304	Poly (Vinyl Chloride) (PVC) Profile Wall Drain Pipe and Fittings Based on Controlled Inside Diameter	Corrugated
ASTM F 949	Poly (Vinyl Chloride) (PVC) Corrugated Sewer Pipe with\ a Smooth Interior and Fittings	Corrugated
ASTM F 789	Type PS-46 and Type PS-115 Poly(Vinyl Chloride) PVC Plastic Gravity Flow Sewer Pipe and Fittings	PS46
		PS 115
ASTM D 2665	Poly (Vinyl Chloride) (PVC) Plastic Drain, and Vent Pipe and Fittings	Schedule 40

4.3.1.3 Smooth Wall Pipe with Corrugations

A new generation of plastic pipe combines the strength of corrugations with the flow characteristics of smooth pipe. This pipe should conform to **AASHTO M 304 Poly (Vinyl Chloride) (PVC) Profile Wall Drain Pipe and Fittings Based on Controlled Inside Diameter, ASTM F 949 Poly (Vinyl Chloride) (PVC) Corrugated Sewer Pipe with a Smooth Interior and Fittings or AASHTO Specification M 252, Corrugated Polyethylene Drainage Pipe - Type SP** for CPE pipe.

4.3.1.4 Heat Resistant Pipe

If the pipe will be installed in trenches that are to be backfilled with asphalt stabilized permeable material (ASPM), the pipe must be capable of withstanding the temperature of the ASPM.

PVC 90^0 electric plastic conduit, EPC-40 or EPC-80 conforming to the requirements of the National Electrical Manufacturers Association (NEMA) Specification TC-2 is suggested when ASPM is used as a trench backfill.

4.3.2 Pipe Strength

Pipe strength can be determined by, **ASTM D 2412 External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.**

4.3.3 Pipe Openings

The pipe should have 42.32 cm^2 of openings per linear meter (2 sq in/ft) of pipe to allow the discharge water to flow into the edgedrain.

4.4 Trench Design

4.4.1 Trench Backfill

In the pre-pave installation, the edgedrain is installed as the permeable base is being placed. The trench material surrounding the edgedrain pipe is the same as the permeable base material. It is feasible to install the edgedrain in a separate operation. This would allow the trench backfill to be compacted before the permeable base is placed. For this case, the backfill material should be stable and as permeable as the permeable base material.

In the post pave installation, the edgedrain is installed after the pavement has been placed. Placing of the pipe and trench backfill is a second stage operation. Trench backfill material should be stable and at least as permeable as the permeable base material.

4.4.2 Trench Width and Depth

Depending on pipe size, many SHA's use a trench width of 200 to 250 mm (8-10 inches). The trench width must be wide enough to allow proper placement of the pipe and compaction of the backfill material around the pipe.

The trench depth must be deep enough to accomplish the intended drainage function. **It is recommended that the trench depth be deep enough to allow the top of the pipe to be located 50 mm (2 inches) below the bottom of the permeable base.**

4.4.3 Trench Compaction

Adequate compaction of the trench backfill is essential to prevent premature deterioration of the shoulder. Trench backfill should be placed in three layers with compaction being applied after each lift.

4.4.4 Geotextile Placement for Pipe Edgedrains

Geotextile placement will vary depending on whether the edgedrain is installed before or after the construction of the permeable base. This has been discussed in Section 2.2 Pavement Section. **The edgedrain trench should be lined with a geotextile to prevent fines from the surrounding subgrade from entering the pavement section.** The primary purpose of the geotextile is filtration; that is, keeping the fines in the subgrade from contaminating the trench backfill material. The geotextile should have a permeability several times greater than the subgrade soils. Geotextile placement for a pre-installation edgedrain is shown in Figure 4-1.
Since the permeable base should contain no fines, discharge of fines from the permeable base should not be a problem. The top of the trench adjacent to the permeable base is left open to allow a direct path for the water into the edgedrain pipe as shown in Figure 4-1.

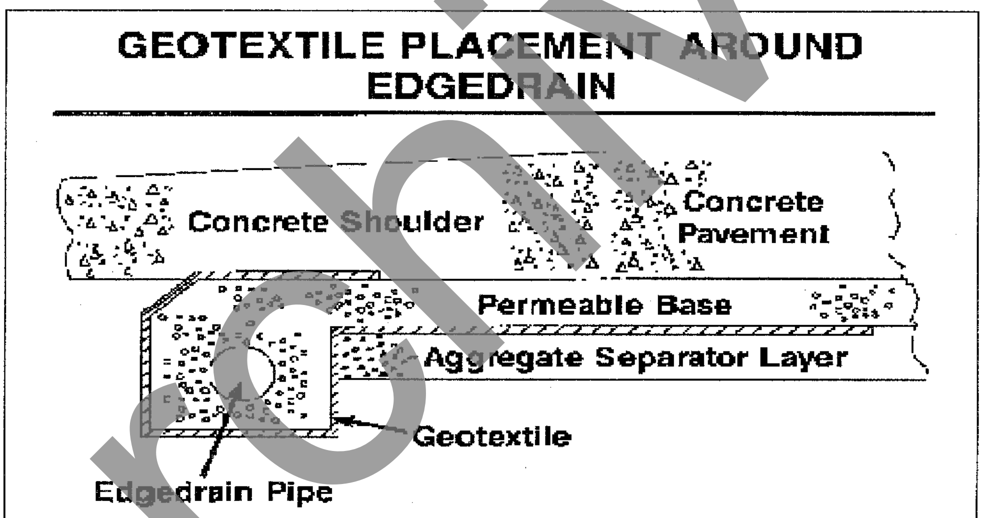

Figure 4-1 Geotextile Placement Around Edgedrain

4.5 Geocomposite Fin Drains

Currently there are a large number of geocomposite fin drains on the market. It is pointed out that selection of the geocomposite fin drain is strictly a "Buyer Beware" scenario. Engineers must determine if the geocomposite has the necessary hydraulic capacity and structural strength to meet its intended role.

Geocomposites are composed of the following two elements:

- Structural Core
- Geotextile Cover

The structural core provides the following three functions:

- Provides structural strength
- Provides a conduit to discharge the water
- Provides a structural skeleton for the geotextile covering

While the geotextile performs the following functions:

- Transmits water into the structural core.
- Retains soil particles

4.5.1 NCHRP Synthesis Report No. 367, Long-Term Performance of Geosynthetics in Drainage Applications

Problems associated with the installation of geocomposite fin drains were studied in depth and reported on in the **NCHRP Synthesis Report No. 367, Long-Term Performance of Geosynthetics in Drainage Applications.** In this study a large number of existing geocomposite edgedrains were exhumed and studied in a forensic approach. This study found many of the edgedrains were crushed or buckled in the installation and backfill process.

However, the report believed that with quality of construction, successful installation could be obtained. The single largest problem encountered was a lack of intimate contact with the expose edge of the pavement structure along with voids created by base material falling away. To solve this problem, the report suggested that the edgedrain location be moved to the far side of the trench and that a sand backfill material be placed between the edgedrain and the exposed pavement edge as shown in Figure 4-2.

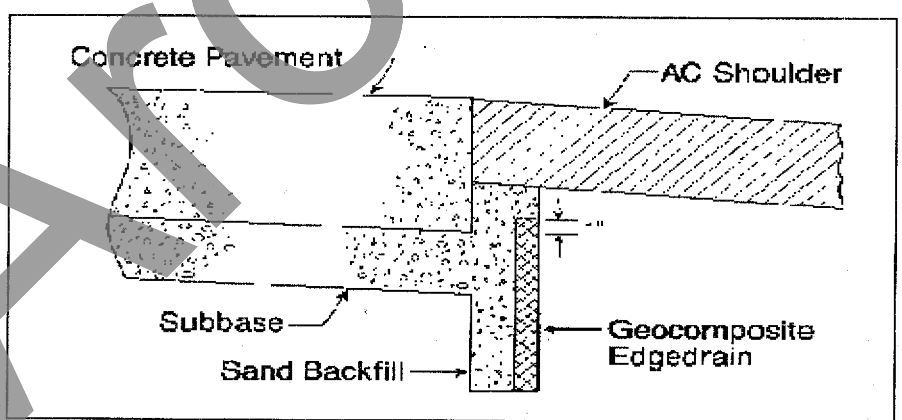

Figure 4-2 Placement of Geocomposite Edgedrain

The report also suggested a gradation for the sand backfill as given in Table 4-2

Table 4-2 Gradation of Sand Backfill

Sieve Size (mm)	Alternate Sieve Designation	Percent Passing
9.5	3/8"	100
4.75	No.4	100 - 95
2.36	No. 8	100 - 80
1.18	No. 16	85 - 50
0.60	No. 30	60 - 25
0.30	No. 50	30 - 10
0.15	No. 100	10 – 2
0.075	No. 200	2 – 0

4.5.2 Hydraulic Capacity

A number of geocomposite manufacturers rate their product's hydraulic capability based on **ASTM D-4716, Constant Head Hydraulic Transitivity (In-Plane Flow) of Geotextiles and Geotextile Related Products**. In this test, the core lies horizontally, and the hydraulic capacity of the geocomposite is determined for a standardized head and length of geocomposite. This test will not determine the hydraulic capacity of a geocomposite in actual field conditions. It is only good for determining the relative hydraulic capacity between two geocomposites under the specific test configuration. It is primarily intended as an index test.

A select number of geocomposites were tested in laboratories to determine their hydraulic capacity in a field configuration. The FHWA microcomputer program **DRIP, Drainage Requirements in Pavements** calculates the hydraulic capacity of these selected geocomposites.

4.6 Lateral Outlet Pipe

Installation of the outlet pipe is critical to the drainage system. It is recommended that a high stiffness polyethylene or PVC non- perforated pipe be used for the outlet pipe to insure proper grade and sufficient stiffness to withstand installation and traffic (mowers) loads without damage or significant deformation. The outlet pipe should have a minimum stiffness of 65 psi. Plastic pipe conforming to **ASTM D 3034-89 Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings** with a Standard Diameter Ratio (SDR) of 23.5 or **ASTM D 2665, Poly(Vinyl Chloride) (PVC) Plastic Drain and Vent Pipe and Fittings,** Schedule 40 are the most rigid plastic pipes produced today.

A 3% positive downward slope of the pipe to the roadside ditch is recommended. This will insure that the pipe will drain if there is a slight variance of the pipe grade.

4.6.1 Surface Water Coordination

It is imperative that the subsurface drainage be coordinated with surface drainage. HEC No. 12, Drainage of Highway Pavements provides guidance for the design of water flowing on pavement surfaces, while **HEC No. 15, Design of Roadside Channels with Flexible Linings** provides guidance for the design of roadside ditches. Most SHA's design surface drainage based on a10-year storm intensity.

Adequate cross slope is the most important item in surface pavement drainage. The pavement cross slope and shoulder slope must be adequate to carry the water away from the traffic lanes. Grass slopes should be as steep as safety considerations allow.

Design of roadside ditches is a trade off of safety considerations, hydraulic design, and drainage of the pavement section. When an edgedrain pipe system is provided, the invert of the roadside ditch may be lowered providing additional internal drainage of the pavement section.

Subsurface drainage design should be coordinated with surface drainage. The invert of the outlet pipe should be at least 150 mm (6 inches) above the 10-year design flow in the ditch. The interface between the outlet pipe and ditch is critical (FHWA 1992). This design arrangement is shown in Figure 4-3.

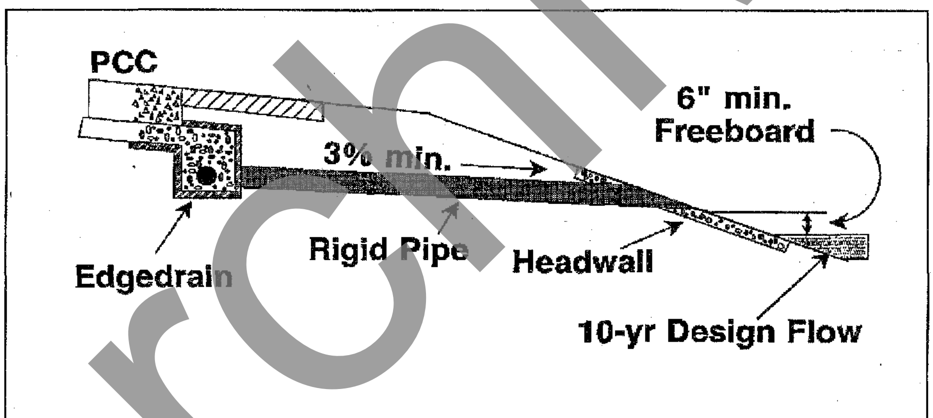

Figure No. 4-3 Outlet Pipe

If roadside ditches or medians are too shallow to outlet the edgedrain system, a storm drain system may have to be installed to collect the water. Surface runoff is collected by storm drain inlets spaced at approximately, 76 m (250 ft); outlet pipes from the longitudinal edgedrain are then connected to the storm drain inlets as shown in Figure 4-4.

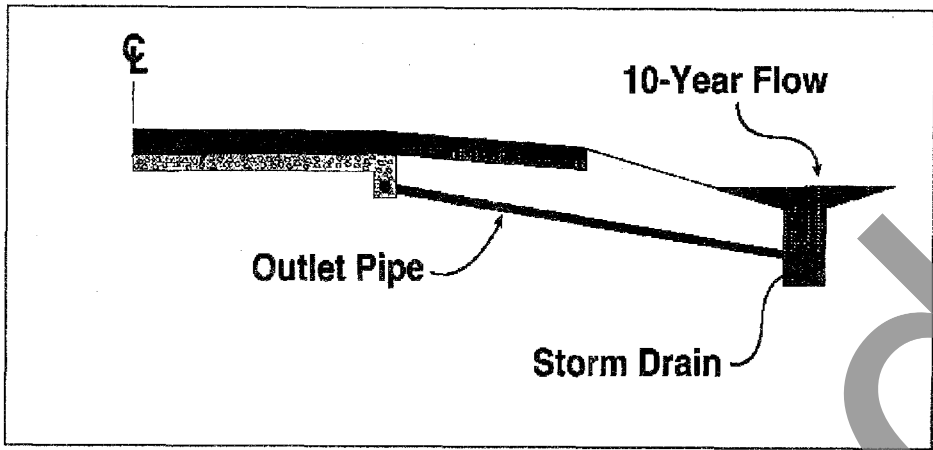

Figure No. 4-4 Outlet Pipe Connected to Storm Drain

4.6.2 Mainline Connection

In the past, the outlet pipes have been connected to the mainline edgedrain using100 x 100 mm (4 x 4-inch) tees. This design is inadequate since maintenance and video inspection equipment cannot make the turn.

The edgedrain pipe system should be designed with maintenance in mind. **An edgedrain system with outlet pipes located at both ends of an edgedrain system should be provided.**

This allows flushing equipment to enter the edgedrain from both ends. A dual outlet approach used by CALTRANS is shown in Figure 4-5 (Baumgardner 1998).

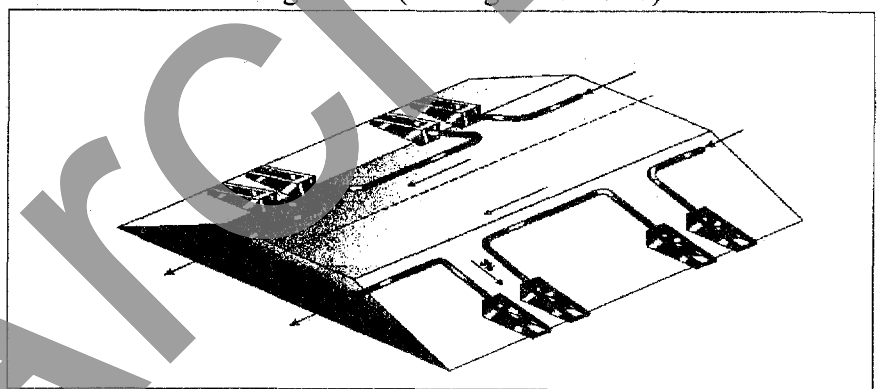

Figure 4-5. Dual Outlet Pipes

Smooth, long radius bends should be provided in the edgedrain system so rodding equipment can negotiate the bends. Radii of 0.6 - 1.0 m (2 to 3 feet) for pipe bends should be used to permit use of jet rodding or cleaning equipment as shown in Figure 4-6 (Baumgardner 1998).

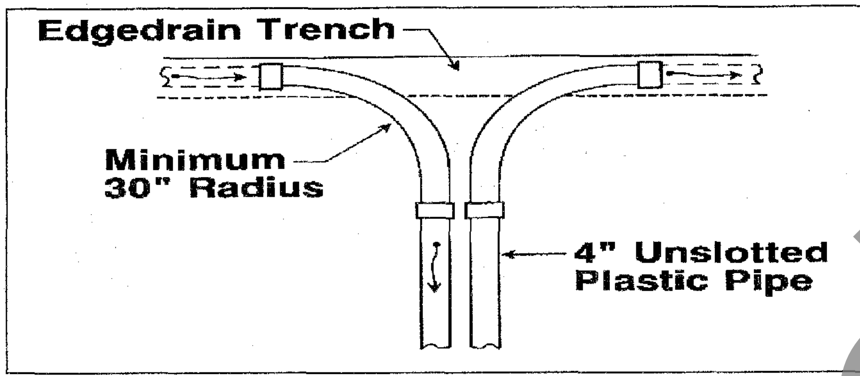

Figure 4-6. Pipe Outlet Bends

A photograph of dual outlets is shown in Photo No. 9.

Photo No. 9 Dual Pipe Outlets

<u>Virginia Dept. of Transportation</u>

The Virginia Department of Transportation has studied the edgedrain problem at some length and has developed a somewhat unique approach to the problem. After investigating almost every edgedrain in their State with video inspection, VDOT adopted the design philosophy that if an adequate outlet and main line connection could be developed, then the edgedrain system would function as intended.

VDOT recognized the benefits of the dual pipe system, but the State believed that the design could be improved. After considerable study, VDOT developed a standard detail for the mainline connection as shown below in Figure 4-7.

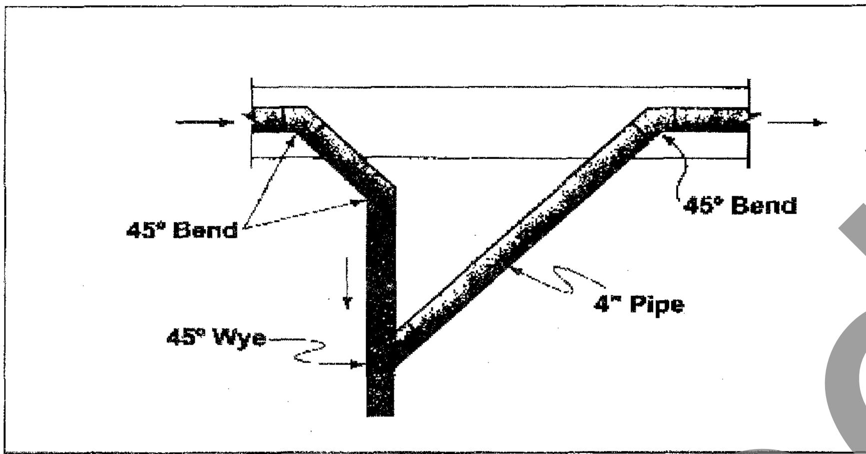

Figure 4-7 VDOT Standard Detail for Mainline Connection

VDOT believes that this design has the following benefits:

- Same hydraulic, maintenance, and inspection capabilities as the curve bends.
- Construction can be accomplished using standard fittings.
- Only one outlet pipe is required.

4.7 Outlet Spacing

The purpose of subsurface drainage is to remove water as quickly as possible; therefore, **outlet spacing should be limited to 76 m (250 ft) based primarily on maintenance considerations.** The edgedrain should be segmented so that each section drains independently.

4.8 Headwalls

Headwalls are recommended because they provide the following functions:

- Protect outlet pipe from damage
- Prevent slope erosion
- Locate outlet pipe for maintenance purposes

Headwalls provide protection of the outlet pipe from being crushed by mowing operations and errant vehicles. Also, the headwall should prevent erosion by spreading out the flow from the outlet pipe. Some engineers recommend large, flush headwalls to keep the vegetative growth away from the outlet pipe. An example of outlet erosion is shown in Photo No. 10.

Photo No. 10 Outlet Erosion

Locating the pipe outlet for maintenance purpose is perhaps the most important function of a headwall. If the outlet pipe cannot be found, there will be no maintenance of the edgedrain system. Large headwalls are the best type of reference markers.

Headwalls should be placed flush with the slope so that mowing operations are not impaired. Both cast-in-place and precast concrete headwalls can be used. The important consideration is that the outlet pipe drains. Some States have used a metal pipe sleeve around the end of the plastic outlet pipe that extends 1.2 to 1.5 m (4-5 ft) into the fill to protect the outlet pipe.

Fabric foam headwalls are fabric sacks that are filled with cement grout. These headwalls are rather large, keeping the vegetative growth away from the outlet pipe. Their size is also a positive factor for controlling outlet erosion and locating the outlet.

4.9 Rodent Screens

Rodent screens are recommended because rodents have been reported to damage geocomposite fin drains and build nests in pipe edgedrains. Eroded fines can build up on the screen and plug the outlet. Rodent screens should be easily removable so that the screens and outlet pipes can be cleaned.

4.10 Reference Markers

Reference markers are recommended since they facilitate locating the outlet pipe for maintenance or observation. Some SHA's use a simple flexible delineator post to mark the outlet, while others use a painted arrow or mark on the shoulder. A headwall will also provide the function of locating the outlet and is perhaps the best reference marker.

4.11 Videotaping for Quality Assurance

Videotaping the completed edgedrain with closed circuit video equipment is suggested for final acceptance of the project. An uniform program of videoing completed projects should improve the quality of both design and construction.

4.12 Construction Considerations

As with any other drainage facility, correct line and grade are critical to the function of the edgedrain. Placement of the outlet pipe in the trench is important; high or low spots in the trench must be avoided. Proper compaction of the trench backfill material is important to prevent future maintenance problems with early deterioration of the shoulder.

ASTM D2321, "Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity Flow Applications" provides excellent guidance for the construction of edgedrains.

For geocomposite fin drains, proper construction cannot be over emphasized since geocomposites are prone to buckle during their placement. **ASTM D 6088, Installation of Geocomposite Pavement Drains** provides good, current guidance for the placement of geocomposite.

To prevent water entrapment, it is critical that the end of the outlet pipe or concrete headwall be constructed to grade so that the pipe drains. If flexible plastic tubing is used for the outlet pipe, pipe curling may be a problem. Concrete headwalls, which have been constructed to grade, should solve this problem. This is one reason why rigid pipe is recommended for the outlet pipe.

Increased emphasis should be placed on better construction and inspection of edgedrain systems, especially the outlets. Proper construction is essential for the edgedrain system to perform as intended.

4.13 Guide Specifications for Edgedrain Acceptance Using Video Inspection

Guide specifications for edgedrain acceptance using video inspection of completed edgedrains are provided in Appendix E.

5.0 VIDEO INSPECTION

5.1 Background

Excavations and inspections of edgedrains have revealed that many of the edgedrain pipe sections have been crushed or clogged. Most likely these problems occurred during the construction of the highway. Advances in video technology have produced a generation of video equipment that is capable of investigating 100 mm (4-inches) diameter pipe.

Under the **"Video Inspection of Highway Edgedrains"** contract, funded by the Federal Highway Administration (FHWA), State highway agencies (SHA's) had their edgedrain systems inspected using closed-circuit video equipment. There were two principal purposes of this project. The first purpose was to provide SHA's with a qualitative video picture of conditions inside the edgedrains, while the second purpose was to demonstrate the technology associated with the video inspection equipment.

5.2 Description of Video Equipment

The equipment consisted of the following three main units: camera head, camera control unit, and a push rod which was coiled on a metal reel.

The camera used was a Pearpoint flexible high resolution, high sensitivity, waterproof, color video camera. Six high intensity lights provided the necessary illumination inside the pipes. The picture was transmitted back to the control module using a closed circuit TV system.

The camera control unit consisted of a TV monitor, video cassette recorder and a keyboard where data concerning the size, type and location of the edgedrain could be entered. The data was then displayed on the video monitor and recorded on the VCR tape and any 35 mm photographs that were taken.

The push rod served two functions. First, the rod was stiff enough to allow the camera operator to push the camera though the edgedrain system. Second, it contained an electrical cable that transmitted the TV signal from the camera to the camera control unit. A mechanical distance counter indicated the distance that the camera head had progressed into the edgedrain system. The push rod was coiled up on a reel; wheels on the storage unit allowed it to be rolled to the edgedrain outlet.

The video inspection equipment was shipped in molded transportation cases that were specially designed for rough handling. The modular nature of the cases made equipment set up easy. The camera control unit which included the video monitor, VCR cassette recorder, and video printer were all located in the master control case. All three units could be accessed by opening the front lid of the case. The case could be wheeled from the van on a dolly to the entrance of the outlet pipe. This allowed the camera operator to watch the video monitor as the push rod was pushed though the edgedrain system.

The light head for the inspection equipment is shown in Photo No.11.

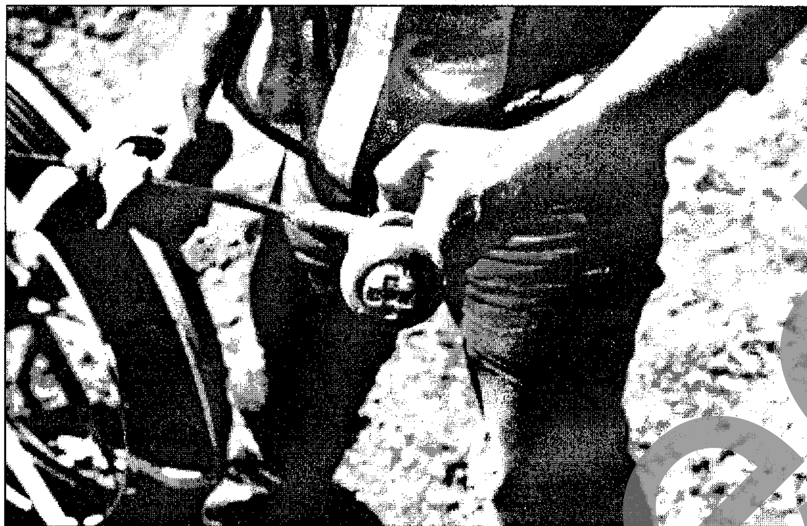

Photo No. 11 Video Inspection Equipment

5.3 Site Investigations

The operator inserted the camera into the outlet pipe and hand-fed the camera up though the edgedrain system. Making the turn from the outlet pipe to the longitudinal edgedrain was particularly difficult if a 100 x 100 mm (4" x 4") tee was used to make the connection. A special tool for making the turn was fashioned by the contractor. Two short sections of 60mm (2-1/2") PVC pipe were screwed together, and a sweep bend was cut off by making a cut parallel with the axis of the pipe. The tool was then inserted into the outlet pipe with the cut-off bend first. The modified bend provided just enough curvature to turn the inspection camera into the longitudinal edgedrain.

The camera operator pushed the inspection camera though the edgedrain system while watching the video monitor. Any sediment build-up or collapsed pipe could be identified on the video monitor while the mechanical distance counter could locate the problem within a meter (3.28 feet). Since the push rod was relatively stiff, the operator could punch through moderate amounts of sediment build-up. In most cases the video inspection continued until a blockage of the pipe was reached.

The entire video inspection was video taped using the VCR cassette recorder. Comments describing any problems encountered could be dubbed into the audio system by the operator. Still photographs could be taken of any blockages that were encountered by using the 35mm color video printer.

5.4 Findings

A host of problems (Daleiden, 1998) were encountered in the video investigations. Below is a representative list of the problems:

- Damaged end of outlet pipe
- Crushed outlet pipes
- Clogged outlet pipes
- Unable to make turn from outlet pipe to mainline edgedrain.
- Sediment blocking mainline edgedrain
- Mainline edgedrain pipe crushed
- Rodent nest blocking pipe
- Standing water in the pipes.

Examples of crushed pipe are shown in Photo's Nos. 12 & 13.

Photo No. 12 Example of a Crushed Pipe

Photo No. 13 Example of a Crushed Pipe

The number and severity of these problems were astonishing. Of the total of 269 pipes that were inspected, 35 percent of the laterals could not be inspected because they were crushed or clogged. The condition of mainline could not be investigated. Another 13 percent of the edgedrains could not be inspected because the camera could not make the turn from the outlet pipe to the mainline edgedrain. This was due to a number of factors such as geocomposite edgedrains, drop tees, drop inlets, no mainline pipe, or the outlet pipe was not connected to the edgedrain. Of the mainlines that could be inspected, 17 percent of the mainlines were blocked or clogged. This means that of all the edgedrains inspected only 35 percent of the pipes could be classified as good. A breakdown of this data is shown in Figure 5-1.

These findings indicate that the current design, construction and maintenance of edgedrain systems is inadequate.

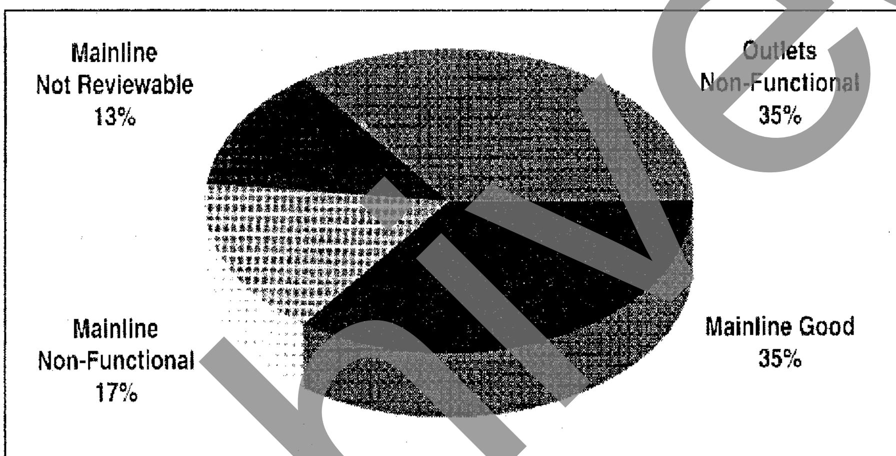

Figure 5-1 Breakdown of Video Inspections

5.5 Quality Assurance

Video inspection of the completed edgedrain is recommended for final acceptance of the project. An uniform program of videoing completed projects should improve the quality of both design and construction. Based on video inspections taken during this contract, it appears that most of the crushed pipes occurred during the construction phase. Since the video equipment has a distance counter, any obstructions can be accurately located and quickly bought to the contractor's attention.

5.6 Maintenance Purposes

Video inspection of highway edgedrains using closed-circuit television is a necessary tool for maintaining the functionality of the edgedrain system. Any developing problem can be identified early on so that remedial work can be performed. The quality of the video picture is adequate enough that the video operator can identify the problem, and with the distance counter can accurately locate it.

5.7 Pavement Management

Edgedrains are an integral part of the highway infrastructure and should be part of any pavement management. Edgedrains should be entered into the pavement management data base and periodically video inspected with video equipment. This will provide the SHA with additional data in evaluating the cost effectiveness of drained versus undrained pavement sections.

5.8 Edgedrain Problems

Based on the findings from this project, and other studies, below is a list of problems encountered with the design, construction and maintenance of highway edgedrain systems:

- Unable to find pipe outlet.
- Entrance of outlet pipe crushed.
- Lateral pipe outlets crushed or clogged.
- Ninety (90) degree tees used to connect the mainline drain to the outlet pipe.
- Inadequate slope on the outlet pipe.
- Flow line of the outlet pipe below the roadside ditch.
- Inadequate maintenance.

Engineers must recognize these problems and provide designs and construction procedures that will eliminate them. Engineers now recognize that although maintenance may be difficult and expensive; it can be accomplished. **The design and construction phases must produce a product that will at least permit maintenance.**

6.0 MAINTENANCE

Maintenance is critical to the continued success of any longitudinal edgedrain system. Inadequate maintenance is a universal problem. The combination of vegetative growth, debris, and fines discharging from the edgedrains will eventually plug the outlet pipe. Mice nests, mowing clippings, and sediment collecting on rodent screens at headwalls are common maintenance problems. Often outlets cannot be found because they are hidden by vegetative growth. Some outlets have been so plugged that water gushed from the pipes when they were unplugged. An example of vegetative material removed from an edgedrain is shown in Photo No.14.

Photo No. 14 Vegetative Material Removed from an Edgedrain System

It is obvious that if maintenance personnel cannot find the outlets, no maintenance can be performed. The SHA's that use concrete headwalls, reference markers, or painted arrows on the shoulders have better success in providing maintenance. It is also important that maintenance activities not block or damage the pipe outlet.

If flexible corrugated plastic pipe has been used as an edgedrain, the pipe will not be perfectly straight since the pipe bends when it encounters any large stones during the laying process. These bends provide an opportunity for sediment to build up in the edgedrain. Periodic flushing of the edgedrain may be necessary to remove sediment build up.

Flushing or jet rodding the system is important in the maintenance scheme. It is important that the pipe have proper bends to facilitate this operation. The edgedrain pipe system should be designed with maintenance in mind. These operations should be done on a routine schedule.

Edgedrain outlets and pipe systems should be inspected at **least once a year** to determine their condition. **Use of video equipment to inspect the edgedrain pipe system is recommended.** Flushing of the pipe systems should be performed as necessary.

Maintenance personnel should mow around the outlet pipes at least twice a year. It is important to perform the mowing on a periodic basis to keep vegetative build up to a minimum. Roadside ditches should also be mowed and kept clean of debris.

NCHRP Synthesis 285 "Maintenance of Highway Edgedrains"

The new NCHRP Synthesis 285, "Maintenance of Highway Edgedrains," provides a very insightful look into the problems associated with edgedrain maintenance. The conclusions listed below are extremely important since they hit at the heart of the problem.

In the area of pavement performance and benefits, the synthesis draws the following conclusions:

- "The cost of maintenance is far outweighed by the anticipated design life of the road that comes with edgedrains that perform."
- There is a significant cost in terms of poor performing pavements to agencies that use edgedrains and do not have an effective preventive maintenance program."
- Long term maintenance is essential to obtain the anticipated benefits of drainable pavement systems."

The merits of pavement subsurface drainage are recognized by the following conclusion:

- Based on the results of "NCHRP Synthesis 239" and confirmed by literature reviewed in this synthesis, there is a significant cost in terms of poor pavement performance to agencies that are not using edge drains."

The need for quality control in construction is acknowledged by the following conclusions:

- Edgedrain failures have occurred where the water could not get out of the base fast enough (e.g., no pipe outlets, plugged outlets, crushed outlets, clogged filters, or clogged drains). Many drainage system failures are traced to poor construction and inspection."
- Training of construction and inspection staff is important to improve drainable pavement performance.
- The need for qualified and trained maintenance personnel is seen in the following conclusion:
- All maintenance personnel should be made aware that a plugged subsurface drainage system may be worse than no drainage system because the pavement system becomes permanently saturated.

Two of the most salient conclusions were:

- Maintenance efforts vary between good and nonexistent within a state and among different states.
- There is an apparent disconnect between maintenance, design and construction in many state agencies.

If a SHA is unwilling to make a maintenance commitment, permeable bases should not be used since the pavement section will become flooded. This will increase the rate of pavement damage (FHWA 1992, Christopher 1997).

7.0 REFERENCES

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APPENDIX

APPENDIX A

GUIDE SPECIFICATION FOR THE CONSTRUCTION OF UNSTABILIZED PERMEABLE BASES

301.01 Description[1]

The work shall consist of constructing a permeable base consisting of non-stabilized aggregates. The aggregate materials shall be blended in a continuous or batch type plant and hauled to the project site and spread in a uniform thickness over a previously constructed aggregate or geotextile separator layer.

301.02 Materials

Aggregate material must be hard, durable material. As a minimum, the aggregate should have at least two fractured faces as determined by the material retained on the 4.75 mm (No. 4) sieve; preferably it should consist of 98 percent crushed stone.

The L.A. abrasion wear should not exceed 45 percent as determined by AASHTO T 96-94 **Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine**.

The soundness percent loss should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectively. The test shall be in accordance with AASHTO T 104-86, **Soundness of Aggregate by the Use of Sodium Sulfate or Magnesium Sulfate**.

301.03 Gradation

The aggregate material's gradation shall conform to the following gradation requirements[2]:

Gradation Requirements for Unstabilized Permeable Base		
Sieve Size (mm)	Sieve Size Alternate Designation	Percent Passing
37.5	1-1/2"	100
25.0	1"	95 – 100
12.5	½"	60 – 80
4.75	No. 4	40 – 55
2.36	No. 8	5 – 25
1.18	No. 16	0 – 8
0.30	No. 50	0 – 5

Note: This gradation can be obtained by using a blend of AASHTO Gradation No. 57 and No. 9 in an approximate 1:1 ratio.

1. Specification is based on the one developed by the New Jersey Dept. of Transportation
2. Gradation based on one developed by the New Jersey Dept. of Transportation

Material passing the 0.425 mm (No. 40) sieve shall be non plastic in accordance with AASHTO T 90-96, **Determining the Plastic Limit and Plasticity Index of Soils**.

301.04 Mix Design

The Contractor shall submit for approval a mix design for the material and a statement naming the source of the material.

The job mix formula shall establish the percentage of dry weight of aggregate passing each sieve size. The job mix formula shall be in effect until modification is approved.

The mix design shall be such that when the component sieve sizes are blended together and compacted with a Burmister Table in accordance with ASTM D 4253-93 **Maximum Index Density and Unit Weight of Soils Using a Vibratory Table** and tested for permeability, its permeability will be 610 meters per day (2,000 feet per day), within a plus (+) or minus (-) 305 meters per day (1000 feet per day).

301.05 Verification of Mix Design

At least 45 days prior to the production of the non-stabilized permeable base materials, the Contractor shall submit for approval, a mix design and the following quantities of components for material testing and verification that the mix design will result in a mixture having the required permeability:

- Blended Aggregate 200 Lbs. or
- Component Size 100 Lbs (each size)

When unsatisfactory results for any specified characteristic of the work make it necessary, the contractor may establish a new mix design for approval by the engineer. In such instances, if the contractor fails to take corrective action, the engineer reserves the right to require an appropriate adjustment.

301.06 Equipment

All equipment necessary to mix, transport, place, compact, and finish the permeable base shall be on the project and approved before work will be permitted to start. Such equipment shall include a stationary or portable continuous or batch type pugmill mixer equipped with batching or metering devices for proportioning the blend or other approved units capable of producing a blended material consistently meeting the gradation requirements. An asphalt paver shall be provided that is capable of maintaining a uniform rate of travel while spreading and laying a lift of uniform consistency and thickness with proper grade control. Motor graders or smooth, steel wheel vibratory roller and other equipment and tools shall be provided as necessary to perform the work in a satisfactory manner.

Construction Requirements

301.07 Preparation of the Aggregate Separator Layer Course

The aggregate separator layer shall be checked and approved far enough in advance of spreading the unstablized aggregate mixture to permit one day's operation, exception being permitted at the discretion of the engineer.

301.08 Mixing

The crushed aggregates shall be blended together in the proper proportions as specified in the mix design.

Surge hoppers shall be used to supply aggregates for blending to meet the required gradation. The blend shall be handed in such a manner as to prevent contamination, degradation, and segregation.

301.09 Quality Control Testing

301.09(a) Conformance to Job Mix Formula

Conformance to the mix design gradation will be determined on the basis of samples taken by the Engineer at the construction site after placement and tested in accordance with ASTM D 421, **Practice for Dry Preparation of Soil Samples for Particle -Size Analysis and Determination of Soil Constants** and ASTM D 422, **Test Methods for Particle-Size Analysis of Soils**.

301.09 (b) Sampling and Testing

Samples shall be taken at a rate of one (1) sample per every 115 cu. meters (150 yd^3) of permeable base material. The producer shall have a quality control technician available at the plant to immediately correct any deficiency in the product.

301.10 Transportation of the Mixture

The blended material shall be hauled to the site in vehicles that will prevent contamination, degradation, and segregation of the material. Any truck causing excessive segregation of the mixture by its suspension or other contributing factors or that leaks and causes delays shall be removed from the work until such conditions are corrected.

Loads shall not be sent out so late in the day as to prevent completion of the spreading and compaction of the mixture during daylight, unless sufficient artificial light is provided.

Plant production and the number of trucks used for transportation shall be such as to ensure delivery of the mixture in sufficient quantities and at such intervals to permit continuous placement of the material with minimal stopping and starting of the paving operation. Failure to maintain such delivery shall be cause to suspend the work.

301.11 Spreading

Plant mixed aggregates should be delivered to the prepared subbase or base course and spread as uniformly as possible with a minimum of manipulation to prevent segregation. The aggregate should be placed in compacted lifts not to exceed 100 mm (4 inches). An asphalt laydown machine with automatic grade control shall be used.

301.12 Compaction, Shaping, and Finishing

301.12(a) Compaction

For unstablized permeable bases, compaction shall consist of one to three passes of a 4.5 to 9 metric ton smooth steel-wheeled power roller to achieve proper densification of the non-stabilized permeable base. Vibratory rollers can be used with care. Over rolling can cause degradation of the aggregate material and a subsequent loss of permeability.

Control Strips

One or more control strips shall be constructed at the beginning of work for the purpose of determining the project's compaction requirements. An additional control strip shall be constructed when a change is made in the type or source of aggregate material, whenever a change occurs in the composition of the material from the same source or as directed. Each control strip shall consist of an area of at least 335 m^2 (400 sq. yd.) and shall be constructed of the same material as that specified for the construction of the project.

The control strip shall be compacted by a minimum of two passes of the compaction equipment. Compaction shall continue until no appreciable increase in density is obtained by additional passes without crushing the aggregate. Density of the control strip shall be determined in accordance with the current provisions of AASHTO T 238 -97, **Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depths**, Method A.

Upon completion of compaction, a minimum of ten (10) tests will be made at random locations to determine the average in-place density of the control strip. The average value shall be reference maximum density for the permeable base material from the same source used elsewhere on the project.

Compaction Acceptance

For purposes of monitoring conformance to the compaction requirements, the non-stabilized, permeable base constructed on the project shall be divided into lots consisting of approximately 4,200 m^2 (5,000 sq.yd.) or less of area.

The engineer shall determine the average lot density of five (5) randomly selected locations in the lot. This average lot density shall not be less than 95% of the Average Reference Maximum Density in the control strip. If a lot fails to meet requirement, it shall be recompacted by the contractor at his expense and shall be resubmitted for acceptance. The engineer shall determine the new average lot density. (If this density still fails to meet 95% of the Average Reference Maximum Density, each SHA should determine the course of action. A penalty or reconstruction of the permeable base may be required.)

301.12(b) Shaping and Finishing

After the aggregate material has been compacted, the surface shall be shaped to the required cross-sections. If the next layer consists of an asphalt concrete material, the non-stabilized base shall be covered with a primecoat.

301.13 Tolerances

301.13(a) Surface Variation

The surface tolerance shall be within a plus (+) or minus (-) 10 mm (3/8"). Low areas shall be corrected by adding material, grading and compacting.

301.13(b) Thickness

The thickness tolerance shall be within a plus (+) or minus (-)13 mm (½"). Thin areas shall be corrected by adding material, grading and compacting.

301.14 Maintenance under Traffic

Maintenance of the permeable base shall be performed during its construction and until the Contractor has entirely covered the course with pavement or the next layer. It shall be the Contractor's responsibility to maintain drainage of the job site such that any fine material is not allowed to wash into and clog any part of the drainage system. Any area of the permeable base that becomes clogged shall be reconstructed.

If a Portland cement concrete pavement is to be placed on top of the non-stabilized permeable base, no construction traffic shall be allowed on the permeable base. All concrete delivery trucks shall deliver their concrete to the paver in a side-deliver operation. The width of the concrete paver should be such that the paver completely spans the permeable base with the paver tracks running on the dense graded aggregate base.

If an asphalt concrete pavement is to be placed on top of the non-stabilized permeable base, only the construction traffic necessary to construct the pavement shall be allowed on the permeable base.

In no case shall the edges of the permeable base be left unprotected and subject to infiltration. The non-stabilized permeable base shall be completely paved within two (2) weeks following its completion.

Compensation

301.15 Method of Payment

Non-stabilized permeable base material of the various thickness, will be measured by the square meter (sq. yd.).

Payment will be made under:

- **Pay Item**
  - Non Stabilized base materials
- **Pay Unit**
  - Square Meter (square yard)

APPENDIX B

GUIDE SPECIFICATION FOR THE CONSTRUCTION OF ASPHALT STABILIZED PERMEABLE BASES

301.01 Description[1]

The work shall consist of constructing a permeable base consisting of asphalt stabilized aggregates. Work shall consist of mixing the aggregate and asphalt in a continuous or batch type plant and transporting it to the project site and spreading it in a uniform thickness over a previously constructed aggregate or geotextile separator layer.

301.02 Materials

301.02(a) Aggregates

Aggregate material must be hard, durable material; it should consist of 98 percent crushed stone.

The L.A. abrasion wear should not exceed 45 percent as determined by AASHTO T 96-94, **Resistance to Abrasion of Small Size Course Aggregate by Use of the Los Angles Machine**.

The soundness percent loss should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectfully. The test shall be in accordance with AASHTO T 104-86, **Soundness of Aggregate by the Use of Sodium Sulfate or Magnesium Sulfate**.

301.02(b) Asphalt

Asphalt cement as described in AASHTO MPI-98, **"Performance Graded Asphalt Binder;"** Grades PG 76-22, 70-22 or 64-22 may be used as conditions warrant.

301.02 (c) Application Rate

The asphalt content shall be 3 percent plus ± ½ percent by weight of dry aggregate and mineral filler.

301.03 Gradation

The asphalt stabilized materials gradation shall conform to the following gradation[2] requirements:

1. Overall format of the specification is based on the one developed by the New Jersey Dept. of Transportation.

2. Gradation is based on the one developed by the New Jersey Dept. of Transportation.

Gradation Requirements for Asphalt Stabilized Permeable Base		
Sieve Size (mm)	**Sieve Size Alternate Designation**	**Percent Passing**
25.0	1"	100
19.0	3/4"	95 - 100
12.5	½"	85 - 100
4.75	No. 4	15 - 25
2.36	No. 8	2 - 10
0.075	No. 200	2 - 5

301.04 Mix Design

The Contractor shall submit for approval a mix design for the material and a statement naming the source of the material.

The job mix formula shall establish the percentage of dry weight of aggregate passing each required sieve size and the percentage of asphalt based upon the weight of the total mix. The values of percent passing each sieve size shall be within the above gradation band. The job mix formula shall be in effect until modification is approved.

The mix design shall be such that when the component aggregates are blended together, mixed with the specified amount of asphalt at a temperature of 250 degrees F[1] and compacted at the department's laboratory with an Instron machine at 600 psi for carbonate rock aggregate and 1000 psi for aggregates of all other stone types according to ASTM D 1074, **Compressive Strength of Bituminous Mixtures** and tested for permeability, its permeability will be 610 meters per day (2,000 feet per day), within a ± 305 meters per day (1000 feet per day).

Note: FHWA recommends that an additive to prevent stripping of the asphalt cement be used.

301.05 Verification of Mix Design

At least 45 days prior to the production of the asphalt stabilized permeable base materials, the Contractor shall submit for approval, a mix design and the following quantities of components for material testing and verification that the mix design will result in a mixture having the required permeability:

- Blended Aggregate, 90.8 kg (200 lbs)
- Asphalt Materials, 1 gal.

1. Values based on specifications developed by the New Jersey Dept. of Transportation (Higher temperatures will be needed when using PG 76-xx or PG 70-xx grades of asphalt cement).

When unsatisfactory results for any specified characteristic of the work make it necessary, the contractor may establish a new mix design for approval by the engineer. In such instances, if the contractor fails to take corrective action, the engineer reserves the right to require an appropriate adjustment.

301.06 Equipment

All equipment necessary to mix, transport, place, compact, and finish the permeable base shall be on the project and approved before work will be permitted to start. Such equipment shall include a stationary or portable continuous or batch type pugmill mixer equipped with batching or metering devices for proportioning the blend or other approved units capable of producing a blended material consistently meeting the gradation requirements, a traveling plant such as an asphalt laydown machine capable of maintaining a uniform rate of travel while spreading and laying a lift of uniform consistency and thickness with proper grade control, motor graders or steel wheel vibratory roller and other equipment and tools as may the required to perform the work in a satisfactory manner.

Construction Requirements

301.07 Preparation of the Base Course

The base course shall be checked and approved far enough in advance of spreading the asphalt mixture to permit one day's operation, exception being permitted at the discretion of the engineer.

A prime coat shall be applied to the aggregate separator layer.

301.08 Preparation of the Asphalt Cement Mixture

The dried aggregates shall be combined in the mixer in the amount of each fraction to meet the job mix formula. The asphalt cement material shall be weighed or metered and introduced into the mixer in the amount specified.

The temperature at the discharge from the plant or surge and storage bins shall be maintained between 135 to 165 degrees C.[1] (275-325 degrees F.). Since the stiffer PG 76-xx or 70-xx grade asphalt is used, this temperature is necessary to coat the aggregates with asphalt and insure a homogenous mix.

301.09 Quality Control Testing

301.09(a) Conformance to Job Mix Formula

Conformance to the job mix formula will be determined on the basis of extraction samples taken and tested at the mixing plant for manual batch plants and will be determined by plant printout tickets and hot bin samples for fully automated batch plants. If samples are found to be outside of the master gradation band on any sieve content, the producer shall correct the deficiency before continuing production.

301.09(b) Sampling and Testing

Sampling rates and testing for asphalt content and conformance to the gradation master band for manual and automated batch plants and drum mix plants shall be in accordance with the State highway agencies' standard specifications.

For process control purposes at manual batch plants, the producers quality control technician will sample and determine the gradation of aggregate components in the hot bin at least twice daily during continuous production of asphalt stabilized permeable base materials. At drum mix plants, this process control sampling and testing shall be performed on material in the cold bins. The resulting bin gradations shall be theoretically combined using the mix formula bin pulls to determine if changes are needed in the aggregate blending process. Process changes shall be made by the producer to keep the mixture in gradation control.

301.10 Transportation of the Mixture

The mixture shall be transported from the mixing plant to the project in trucks equipped with tight, clean bodies which shall be lightly coated with a soap or lime solution or other such non-petroleum-based release agent. Each truckload of mixture delivered shall be covered with a waterproof canvas tarpaulin or other such material of such size and so fastened, as to protect the mixture from the weather. Any truck causing excessive segregation of the mixture by its suspension or other contributing factors or that leaks or causes delays shall be removed from the work until such conditions are corrected.

Loads shall not be sent out so late in the day as to prevent completion of the spreading and compaction of the mixture during daylight, unless sufficient artificial light is provided.

Plant production and the number of trucks used for transportation shall be such as to ensure delivery of the mixture in sufficient quantities and at such intervals to permit continuous placement of the material with minimal stopping and starting of the paving operation. Failure to maintain such delivery shall be cause to suspend the work.

301.11 Spreading

Plant mixed aggregates should be delivered to the prepared subbase or base course and spread as uniformly as possible with a minimum of manipulation to prevent segregation. The aggregate should be placed in compacted lifts not to exceed 100 mm (4 inches). A minimum thickness of 3 - 4 inches (75 - 100 mm) is suggested to provide adequate drainage. An asphalt laydown machine with automatic grade control shall be used.

1. Values are based on the specification developed by the California Dept. of Transportation.

301.12 Compaction, Shaping, and Finishing

301.12(a) Compaction

For asphalt stabilized permeable bases, compaction shall consist of one to three passes of a 4.5 to 9 metric ton smooth, steel-wheeled power roller to achieve proper densification of the permeable base. Vibratory roller may be used in the static mode. Over rolling can cause degradation, over densification and a subsequent loss of permeability.

The asphalt stabilized material shall be spread at a temperature between 93 -120 degrees C. (200-250 degrees F)[1] as measured in the hopper of the paving machine. Compaction of the permeable base should begin when the temperature of the mix has cooled to 65 degrees C. (150 degrees F.)[1] And should be completed before the temperature falls below 38 degrees C. (100 degrees F.)[1].

Control Strips

One or more control strips shall be constructed at the beginning of work for the purpose of determining the project's compaction requirements. An additional control strip shall be constructed when a change is made in the type or source of aggregate material, whenever a change occurs in the composition of the material from the same source or as directed. Each control strip shall consist of an area of at least 335 m^2 (400 square yards) and shall be constructed of the same material and thickness as that specified for the construction of the project.

The control strip shall be compacted by a minimum of two passes of the compaction equipment. Compaction shall continue until no appreciable increase in density is obtained by additional passes without crushing the aggregate. Density of the control strip shall be determined in accordance with the current provisions of AASHTO T 238-97, **Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depths)**, Method A.

Upon completion of compaction, a minimum of ten (10) tests will be made at random locations to determine the average in-place density of the control strip. The average value shall be Average Reference Maximum Density for the permeable base material from the same source used elsewhere on the project.

Compaction Acceptance

For purposes of monitoring conformance to the compaction requirements, the asphalt stabilized, permeable base constructed on the project shall be divided into lots consisting of approximately 4,200 m^2 (5,000 sq.yd.) or less of area.

The engineer shall determine the average lot density of five (5) randomly selected locations in the lot. This average lot density shall not be less than 95 percent of the Average Reference Maximum Density in the control strip. Densities shall be determined in accordance with the

1. **Values are based on the specification developed by the California Dept. of Transportation.**

current provisions of **AASHTO T 238-97,<u>Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depths)</u>, Method A. If a lot fails to meet requirement, it shall be recompacted by the contractor at his expense and shall be resubmitted for acceptance. The engineer shall determine the new average lot density.**

301.12 (b) Shaping and Finishing

After the aggregate material has been compacted, the surface shall be shaped to the required cross-sections. If the next layer consists of an asphalt concrete material, the asphalt stabilized base shall be covered with a prime coat.

301.13 Tolerances

301.13(a) Surface Variation

The surface will be tested using a (10 foot) straight edge at selected locations. The variation of the surface from the testing edge of the straight between any two (2) contacts with the surface shall at no point exceed 10 mm (3/8 inch). All humps or depressions exceeding 9.5 mm (3/8 inch) shall be corrected by removing defective work and replacing it with new material. The rutting tolerance shall be 10 mm (3/8 inch).

301.13(b) Thickness

The thickness tolerance shall be within a plus ± 13 mm (½"). Thin areas shall be corrected by adding material, grading and compacting.

301.14 Maintenance under Traffic

Maintenance of the permeable base shall be performed during the construction of the permeable base and until the Contractor has entirely covered the course with pavement or the next layer .It shall be the Contractors responsibility to maintain drainage of the job site such that any fine material is not allowed to wash into and clog any part of the drainage system. Any area of the permeable base that becomes clogged shall be reconstructed at no additional cost to the state.

In no case shall any construction traffic be allowed on the completed asphalt stabilized permeable base for the first 24 hours.

Only that equipment necessary for the construction of the next higher pavement course shall be allowed on the completed asphalt stabilized permeable base.

In no case shall the edges of the permeable base be left unprotected and subject to infiltration. The open-graded permeable base shall be completely paved within two (2) weeks following its completion.

Compensation

301.15 Method of Payment

Payment will be made under:

- **Pay Item**
  - Asphalt stabilized, permeable base
- **Pay Unit**
  - Asphalt stabilized permeable base material will be measured by the metric ton (ton).

APPENDIX C

GUIDE SPECIFICATION FOR THE CONSTRUCTION OF CEMENT STABILIZED PERMEABLE BASES

301.01 Description[1]

The work shall consist of constructing a permeable base consisting of cement stabilized aggregates. Work shall consist of mixing the aggregate and cement in a continuous or batch type plant and transporting it to the project site and spreading it in a uniform thickness over a previously constructed aggregate or geotextile separator layer.

301.02 Materials

301.02 (a) Aggregates

Aggregate material must be hard, durable material; it should consist of 98 percent crushed stone.

The L.A. abrasion wear should not exceed 45 percent as determined by AASHTO T 96-94, **Resistance to Abrasion of Small Size Course Aggregate by Use of the Los Angles Machine**.

The soundness percent loss should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectfully. The test shall be in accordance with AASHTO T 104-86, **Soundness of Aggregate by the Use of Sodium Sulfate or Magnesium Sulfate**.

301.02 (b) Cement

Cement shall be Type I, Type I-P or Type II[1] conforming to the appropriate sections of the State highway agencies' standard specifications or ASTM C 150-97, **Portland Cement**.

301.02 (c) Curing Compound

Curing materials shall be white pigmented wax base concrete curing compound meeting the requirements of ASTM C-309-94, **Liquid Membrane-Forming Compound for Curing Concrete**.

1. Specification is based on one developed by the Virginia Dept. of Transportation.

301.02(d) Application Rate

The minimum cement content shall be 140 kg per cu. meter[1] (235 lbs. / yd^3, or 2.5 bags / yd^3). Water/cement ratio shall provide for 100% cement paste coverage the aggregate material without significant runoff of the cement/water portion of the mixture during transportation and placement.

Consistency of the mixture shall provide for the minimum amount of water consistent with the required workability to provide a uniform material and surface texture as determined though visual inspection by the Engineer.

If required, the minimum application rate for the curing compound shall be 3.68 sq. meters per liter[1] (16.5 sq. yd per gal.).

301.03 Gradation

The cement stabilized material's gradation shall conform to the following gradation (AASHTO No. 57) requirements, or the following alternate gradation (AASHTO No. 67).

Gradation Requirements for Cement Stabilized Permeable Base (AASHTO No. 57)		
Sieve Size (mm)	**Sieve Size Alternate Designation**	**Percent Passing**
37.5	1-1/2"	100
25.0	1"	95 - 100
12.5	½"	25 - 60
4.75	No. 4	0 - 10
2.36	No. 8	0 - 5

Gradation Requirements for Cement Stabilized Permeable Base (AASHTO No. 67)		
Sieve Size (mm)	**Sieve Size Alternate Designation**	**Percent Passing**
25.0	1"	100
19.0	3/4"	90 - 100
9.5	3/8"	20 - 55
4.75	No. 4	15 - 25
2.36	No. 8	2 - 10
0.075	No. 200	2 - 5

1. Values based on specification developed by Virginia Dept. of Transportation

301.04 Mix Design

The Contractor shall submit for approval a mix design for the material and a statement naming the source of the material.

The job mix formula shall establish the percentage of dry weight of aggregate passing each required sieve size and the percent age of cement based upon the weight of the total mix. The values of percent passing each sieve size shall be within the above gradation band. The job mix formula shall be in effect until modification is approved.

The mix design shall be such that when tested for permeability, its permeability will be 610 meters per day (2,000 feet per day), within a plus (+) or minus (-) 305 meters per day (1000 feet per day).

301.05 Verification of Mix Design

At least 45 days prior to the production of the cement stabilized permeable base materials, the Contractor shall submit for approval, a mix design that will result in a mixture having the required permeability.

When unsatisfactory results for any specified characteristic of the work make it necessary, the contractor may establish a new mix design for approval by the engineer. In such instances, if the contractor fails to take corrective action, the engineer reserves the right to require an appropriate adjustment.

301.06 Equipment

All equipment necessary to mix, transport, place, compact, and finish the permeable base shall be on the project and approved before work will be permitted to start. Such equipment shall include a stationary or portable continuous or batch type pugmill mixer equipped with batching or metering devices for proportioning the blend or other approved units capable of producing a blended material consistently meeting the gradation requirements. A concrete paver shall be provided that is capable of maintaining a uniform rate of travel while spreading and laying a lift of uniform consistency and thickness with proper grade control. Concrete pavers shall be equipped with vibrating screeds or plates for consolidating the permeable base material. Motor graders or smooth, steel wheel vibratory roller and other equipment and tools as may be required shall be provided to perform the work in a satisfactory manner.

1. Values based on specifications developed by the Virginia Dept. of Transportation at the discretion of the engineer.

Construction Requirements

301.07 Preparation of the Aggregate Separator Layer

The aggregate separator layer course shall be checked and approved far enough in advance of spreading the cement stabilized mixture to permit one day's operation, exception being permitted

301.08 Preparation of the Cement Stabilized Mixture

The dried aggregates shall be combined in the mixer in the amount of each fraction to meet the job mix formula. The cement material shall be weighed or metered and introduced into the mixer in the amount specified.

301.09 Placement Temperature

At the time of placing the temperature of the mixture shall be not less than 4 degrees C (40 degrees F) or greater than 35 degrees C (95 degrees F)

301.10 Quality Control Testing

301.10(a) Conformance to Job Mix Formula

Conformance to the job mix formula will be determined on the basis of extraction samples taken and tested at the mixing plant for manual batch plants and will be determined by plant printout tickets and hot bin samples for fully automated batch plants. If samples are found to be outside of the master gradation band on any sieve content, the producer shall correct the deficiency before continuing production.

301.10(b) Sampling and Testing

Sampling rates and testing for cement content and conformance to the gradation master band for manual and automated batch plants and drum mix plants shall be in accordance with the State highway agencies' standard specifications.

For process control purposes at manual batch plants, the producers quality control technician will sample and determine the gradation of aggregate components in the hot bin at least twice daily during continuous production of cement stabilized permeable base materials. At drum mix plants, this process control sampling and testing shall be performed on material in the cold bins. The resulting bin gradations shall be theoretically combined using the mix formula bin pulls to determine if changes are needed in the aggregate blending process. Process changes shall be made by the producer to keep the mixture in gradation control.

301.11 Transportation of the Mixture

The cement stabilized material shall be hauled to the site in vehicles that will prevent contamination, degradation, and segregation of the mixture. Any truck causing excessive segregation of the mixture by its suspension or other contributing factors or that leaks or causes delays shall be removed from the work until such conditions are corrected.

Loads shall not be sent out so late in the day as to prevent completion of the spreading and compaction of the mixture during daylight, unless sufficient artificial light is provided.

Plant production and the number of trucks used for transportation shall be such as to ensure delivery of the mixture in sufficient quantities and at such intervals to permit continuous placement of the material with minimal stopping and starting of the paving operation. Failure to maintain such delivery shall be cause to suspend the work.

301.10 Spreading

Plant mixed aggregates should be delivered to the prepared subbase or base course and spread as uniformly as possible with a minimum of manipulation to prevent segregation. The aggregate should be placed in compacted lifts not to exceed 100 mm (4 inches). A concrete paver with vibrating screeds and automatic grade control shall be used.

301.11 Consolidation, Curing, Shaping, and Finishing

301.11(a) Consolidation

Approved concrete pavers with vibrating screeds or plate vibrators shall be used to place and consolidate the cement stabilized material. Screed or plate vibrators shall be used to consolidate the material to a consistent finish across the width of the course. The material shall not be compacted to the point that it is not free draining or that the aggregate is crushed.

Control Strips

One or more control strips shall be constructed at the beginning of work for the purpose of determining the project's compaction requirements. An additional control strip shall be constructed when a change is made in the type or source of aggregate material, whenever a change occurs in the composition of the material from the same source or as directed. Each control strip shall consist of an area of at least 335 m^2 (400 square yards) and shall be constructed of the same material and thickness as that specified for the construction of the project.

Upon completion of the control section, a minimum of four (4) test for minimum cement content shall be taken. The mean result of four (4) tests shall be within $\pm$ 17.80 kg/m^3 (30 lbs. per yd^3) of the minimum cement content.

Consolidation Acceptance

Acceptance of aggregate coating in cement stabilized permeable base material will be based on the mean results of tests for the minimum cement content performed on samples taken in a stratified random manner from each lot. The rate of sampling will be four (4) per lot. A lot measurement is defined as 2,000 metric tons of material.

A lot will be considered to be acceptable if the mean result of four (4) tests is within $\pm$ 17.80 kg/m^3 (30 lbs / yd^3) of the minimum cement content. If a individual test result indicates that the cement content of the material is deficient by more than 21 kg/m^3 (35 lbs / yd^3) from the design cement content, that portion of the material represented by the sample will be considered a separate part of the lot and may be removed from the roadway at the discretion of the Engineer.

If the value of the test falls below the minimum cement content, a payment adjustment will be applied to the contract unit price based on the following table:

Minimum Cement Content		**Payment Adjustment**
131 - 140 kg/m^3	220 - 235 lbs./yd^3	0%
128 - 130 kg/m^3	215 - 219 lbs./yd^3	4%
125 - 127 kg/m^3	210 - 214 lbs./yd^3	6%
122 - 124 kg/m^3	205 - 209 lbs./yd^3	8%

The adjustment will be applied to the tonnage represented by the samples.

301.11(b) Curing

If curing is a requirement by the engineer, it shall be accomplished by, a fine spray mist, or a curing compound.

301.11(c) Shaping and Finishing

After the aggregate material has been compacted, the surface shall be shaped to the required cross-sections.

Note: Use Corps of Engineers Guidelines for choke stone to reduce yield loss and minimize reflective cracking potential.

301.12 Tolerances

301.12(a) Surface Variation

The surface will be tested using a 3 meters (10 foot) straight edge at selected locations. The variation of the surface from the testing edge of the straight between any two (2) contacts with the surface shall at no point exceed 10 mm (3/8 inch). All humps or depressions exceeding 9.5 mm (3/8 inch), shall be corrected by removing defective work and replacing it with new material. The rutting tolerance shall be 10 mm (3/8 inch).

301.12(b) Thickness

The thickness tolerance shall be within ± 13 mm (½"). Thin areas shall be corrected by adding material, grading and compacting.

301.13 Maintenance under Traffic

Maintenance of the permeable base shall be performed during the construction of the permeable base and until the Contractor has entirely covered the course with pavement or the next layer. It shall be the Contractors responsibility to maintain drainage of the job site such that any fine material is not allowed to wash into and clog any part of the drainage system. Any area of the permeable base that becomes clogged shall be reconstructed at no additional cost to the state.

In no case shall construction traffic be allowed on the cement stabilized permeable base during the first three (3) days of curing.

Only that equipment necessary for the construction of the next higher pavement course shall be allowed on the completed cement stabilized permeable base.

In no case shall the edges of the permeable base be left unprotected and subject to infiltration. The open-graded permeable base shall be completed paved within two (2) weeks following its completion.

Compensation

301.14 Method of Payment

Cement stabilized permeable base material will be measured by the metric ton (ton).

Payment will be made under:

- **Pay Item**
  - Cement stabilized permeable base materials
- **Pay Unit**
  - Metric ton (ton)

APPENDIX D

GUIDE SPECIFICATION FOR THE CONSTRUCTION OF DENSE GRADED AGGREGATE BASES

301.01 Description[1]

The work shall consist of constructing a dense graded aggregate base which will serve as a separator layer between the subgrade and the permeable base. The aggregate materials shall be blended in a continuous or batch type plant and hauled to the project site and spread in a uniform thickness over a previously prepared subgrade.

301.02 Materials

Aggregate material must be hard, durable material. As a minimum, the aggregate should have at least two fractured faces as determined by the material retained on the 4.75 mm (No. 4) sieve; preferably it should consist of 98 percent crushed stone.

301.03 Gradation

The aggregate material's gradation shall conform to the following gradation[1] requirements:

Gradation Requirements for Dense Graded Aggregate Base		
Sieve Size (mm)	**Sieve Size Alternate Designation**	**Percent Passing**
37.5	1-1/2"	100
25.0	1"	95 - 100
19.0	3/4"	55 - 90
4.75	No. 4	25 - 60
0.30	No. 50	5 - 25
0.075	No. 200	3 - 12

The L.A. abrasion wear should not exceed 50 percent as determined by AASHTO T 96-94 **Resistance to Abrasion of Small Size Course Aggregate by Use of the Los Angles Machine**.

Material passing the 0.425 mm (No. 40) sieve shall be non-plastic in accordance with AASHTO T 90-96, **Determining the Plastic Limit and Plasticity Index of Soils**.

The soundness percent loss should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectfully. The test shall be in accordance with AASHTO T 104-86, **Soundness of Aggregate by the Use of Sodium Sulfate or Magnesium Sulfate**

1. Specification is based on the one developed by the New Jersey Dept. of Transportation

301.04 Mix Design

The Contractor shall submit for approval a mix design for the material and a statement naming the source of the material.

The job mix formula shall establish the percentage of dry weight of aggregate passing each sieve size. The values of percent passing each sieve size shall be within the master band. The job mix formula shall be in effect until modification is approved.

301.05 Verification of Mix Design

At least 45 days prior to the production of the non-stabilized permeable base materials, the Contractor shall submit for approval, a mix design and the following quantities of components for material testing and verification that the mix design will result in a mixture having the required permeability:

- Blended Aggregate
- 90.8 kg (200 lbs).

When unsatisfactory results for any specified characteristic of the work make it necessary, the contractor may establish a new mix design for approval by the engineer. In such instances, if the contractor fails to take corrective action, the engineer reserves the right to require an appropriate adjustment.

301.06 Equipment

All equipment necessary to mix, transport, place, compact, and finish the permeable base shall be on the project and approved before work will be permitted to start. Such equipment shall include a stationary or portable continuous or batch type pugmill mixer equipped with batching or metering devices for proportioning the blend or other approved units capable of producing a blended material consistently meeting the gradation requirements, a traveling plant such as an asphalt laydown machine capable of maintaining a uniform rate of travel while spreading and laying a lift of uniform consistency and thickness with proper grade control, motor graders or steel wheel vibratory roller and other equipment and tools as may the required to perform the work in a satisfactory manner.

Construction Requirements

1. Gradation based on gradation developed by New Jersey Dept. of Transportation. The blend shall be handed in such a manner as to prevent contamination, degradation, and segregation.

301.07 Mixing

The crushed aggregates shall be blended together in the proper proportions as specified in the mix design.

301.08 Quality Control Testing

301.08(a) Conformance to Job Mix Formula

Conformance to the mix design gradation will be determined on the basis of samples taken by the Engineer at the construction site after placement and tested in accordance with ASTM D 421, **Practice for Dry Preparation of Soil Samples for Particle -Size Analysis and Determination of Soil Constants** and ASTM D 422, **Test Methods for Particle-Size Analysis of Soils**.

301.08(b) Sampling and Testing

Samples shall be taken at a rate of one (1) sample per every 150 cu. yds. of permeable base material. The producer shall have a quality control technician available at the plant to immediately correct any deficiency in the product.

301.09 Transportation of the Mixture

The blended material shall be hauled to the site in vehicles that will prevent contamination, degradation, and segregation of the material. Any truck causing excessive segregation of the mixture by its suspension or other contributing factors or that leaks or causes delays shall be removed from the work until such conditions are corrected.

Loads shall not be sent out so late in the day as to prevent completion of the spreading and compaction of the material during daylight, unless sufficient artificial light is provided.

Plant production and the number of trucks used for transportation shall be such as to ensure delivery of the mixture in sufficient quantities and at such intervals to permit continuous placement of the material with minimum stopping and starting of the paving operation. Failure to maintain such delivery shall be cause to suspend the work.

301.10 Spreading

Plant mixed aggregates should be delivered to the prepared subbase or base course and spread as uniformly as possible with a minimum of manipulation to prevent segregation. The aggregate should be placed in compacted lifts not to exceed 100 mm (4 inches). An asphalt laydown machine with automatic grade control shall be used.

301.11 Compaction, Shaping, and Finishing

301.11(a) Compaction

The maximum density of the aggregate separator layer material should be determined in the laboratory by AASHTO T 180-97, **The Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457 mm 18-in Drop**, Method C.

Compaction of the aggregate separator layer shall continue until the material complies with the compaction acceptance criteria listed below. The in-place density of the aggregate separator layer shall be determined in accordance with AASHTO T 191-93, **Density of Soil in Place by the Sand Cone Method**, AASHTO T 205-86, **Density of Soil In-Place by the Rubber Balloon Method**, or AASHTO T 238- 97, **Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depths)**, Method B and except that only one method will be used through out the project. Moisture content shall be determined by AASHTO T239-97, **Moisture Content of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depth)**

The aggregate separator layer shall be constructed in layers not exceeding a compacted thickness of 8-inches.

Water shall be applied uniformly over the materials during compaction in the amount necessary to obtain the required density.

Control Strips

One or more control strips shall be constructed at the beginning of work for the purpose of determining the project's compaction requirements. An additional control strip shall be constructed when a change is made in the type or source of aggregate material, whenever a change occurs in the composition of the material from the same source or as directed. Each control strip shall consist of an area of at least 335 m^2 (400 square yards) and shall be constructed of the same material as that specified for the construction of the project.

The control strip shall be compacted by a minimum of two passes of the compaction equipment. Compaction shall continue until no appreciable increase in density is obtained by additional passes.

Upon completion of compaction, a minimum of ten (10) tests will be made at random locations to determine the average in-place density of the control strip. In-place density of the control strip shall be determined in accordance with the current provisions of one of the AASHTO tests listed above (AASHTO T 191-93, T 20-5-86, or T 238-97). If the average density of the material in the control strip is equal to or greater than 95 percent of the aggregate materials maximum density, then the value of the average shall be the Average Reference Maximum Density for the aggregate separator layer. If the control strip does not meet this density, the compaction equipment and or its method of use shall be rejected.

Compaction Acceptance
For purposes of monitoring conformance to the compaction requirements, the aggregate separator layer constructed on the project shall be divided into lots consisting of approximately 4,200 m^2 (5,000 sq. yd.) or less of area.

The engineer shall determine the average lot density of five (5) randomly selected locations in the lot. This average lot density shall not be less than 95% of the Average Reference Maximum Density in the control strip taken in accordance with the current provisions of one of the AASHTO tests listed above (AASHTO T 191-93, T 20-5-86, or T 238-97). If a lot fails to meet requirement, it shall be recompacted by the contractor at his expense and shall be resubmitted for acceptance.

301.11(b) Shaping and Finishing

After the aggregate material has been compacted, the surface shall be shaped to the required cross-sections. If the next layer consists of an asphalt concrete material, the dense graded aggregate base shall be covered with a primecoat.

301.12 Tolerances

301.12(a) Surface Variation

The surface tolerance shall be within a plus ± 10 mm (3/8"). Low areas shall be corrected by adding material, grading and compacting.

301.12(b)Thickness

The thickness tolerance shall be within a plus ± 13 mm (½"). Thin areas shall be corrected by adding material, grading and compacting.

301.13 Maintenance under Traffic

Maintenance of the aggregate separator layer shall be performed during its construction and until the Contractor has entirely covered the course with pavement or the next layer .It shall be the Contractors responsibility to maintain drainage of the job site such that any fine material is not allowed to wash into and clog any part of the drainage system.

Compensation

301.14 Method of Payment

Dense graded aggregate base material of the various thickness, will be measured by the square meter (square yard).

Payment will be made under:

- **Pay Item**
  - Dense graded aggregate base material
- **Pay Unit**
  - square meter (square yard)

APPENDIX E

GUIDE SPECIFICATIONS FOR EDGEDRAIN ACCEPTANCE USING VIDEO INSPECTION

Description

This work involves scoping newly completed pipe edgedrain systems with a video camera to determine if the edgedrain system is adequate and functional.

Equipment

The video inspection equipment should consist of the following components:

Camera

The camera shall have high resolution, high sensitivity, waterproof, color video camera engineered to inspect pipes 75 mm (3 inches) to 150 mm (6 inches) in diameter. The lighthead and camera should be capable of negotiating 100 mm x 100 mm (4" x 4") tees. The light head shall be capable of providing enough light to produce a true color picture of the entire surface area periphery of the pipe. The camera shall include a detachable centering device that will center the camera during pipe inspections.

Camera Control Unit

The portable color control unit should include a built-in 200 mm (8 inches) color monitor and controls including remote iris, focus, video input/output, audio in with built-in speaker, and light level intensity control. Two VCR input/output jacks are provided for video recording as well as tape playback verification though the built-in monitor.

Metal Coiler and Push Rod with Counter

The portable coiler shall contain at least 150 meters of integrated semi-rigid push rod and electrical cable with an electro-mechanical distance counter.

Video Cassette Recorder

The video cassette recorder shall be a high quality four head industrial grade VHS type recorder with audio dubbing, still frame, and slow speed capability.

Color Video Printer

A video printer shall be incorporated into the unit, which will allow the technician to obtain color prints of pipe anomalies or problem areas. This system shall provide direct electronic input from the monitor control unit providing a high quality print.

Generator

A compact portable generator shall be provided that is capable of producing 115 volts and the necessary wattage to power the equipment.

Molded Transportation Case

A molded transportation case shall be provided to house the camera control unit, camera, video cassette recorder, and color printer.

Frequency of Inspection

Video camera inspection shall be conducted on all accessible outlet locations up to and including the mainline longitudinal connection. Additionally a minimum of 10% of the longitudinal pipes shall be inspected to assure that both installation procedures and protection measures have produced a functional drainage system.

Inspections should be performed prior to project completion, but after potentially damaging construction operations are completed.

Where an outlet location is inaccessible with the video camera, visual inspection shall include the following as a minimum: slope of endwalls, pipe outfall, conditions of the endwalls, and the existence of rodent screens and outlet markers.

Procedures

Deficiencies found during the inspection shall include, but not be limited to the following:

- Crushed or collapsed pipe (including couplings or other pipe fittings) that prevents passage of the video camera.
- Pipe that is crushed or deformed (including splits and cracks) for a length of 10 meters (33 feet) or greater, but allows passage of the camera.
- Any blockages or sediment buildup caused by rodents nest, open connections, and cracks or splits in the pipe.
- Sags in the longitudinal profile as evidenced by ponding of water for continuous lengths of 3 m (10 feet) or greater.
- Endwalls and/or outlet pipes that are sloped with less than a 2.0% positive slope towards the outlet.
- Inadequate outfall of less than 150 mm (6 inches) from the pipe outlet to the invert of the bottom of the ditch.
- Pipe that has been penetrated by guard rail posts, sign posts, delineator posts, etc.

Deficiencies shall be noted on the inspection report with their corresponding location on the project site, such as station numbers. If there are no deficiencies noted, or the deficiencies are not deemed detrimental to the drainage system, an o.k. entry shall be made under remarks for the particular outlet. Where deficiencies are noted that require corrective action, all efforts to locate and mark the location of the pipe shall be made using the locator purchased with the camera system. In addition, the length from the outlet to any deficiency should be recorded on the test report using the footage counter furnished with the system.

Upon completion of the corrective measures, the deficient locations shall be reinspected and satisfy the original requirements.

Adequate description should be given to each outlet inspected, including station number, direction of lane, location of outlet (median or shoulder), and size of pipe.

Where deficiencies are found, it is where video taping should be used. Data should be entered using the keyboard furnished with the camera system regarding the location and date of the inspection for incorporation into the video tape. The audio microphone should also be used to provide description of the deficiencies.

Reports

The attached form is suggested for reporting the inspection findings. As a minimum, copies of the inspection report shall be distributed to the Project Inspector, Resident Engineer, District Construction Engineer, and the State Materials Engineer.

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Issued: 3/1/99

VIRGINIA DEPARTMENT OF TRANSPORTATION
________________ DISTRICT MATERIALS
UNDERDRAIN INSPECTION REPORT

CONTRACTOR: ______________________

PROJECT NO.: ____________________ UPC NO.: ____________ DATE: ______________________

BY: ______________________ (SIGNATURE)

TYPE UD: ____________________ MEASUREMENT UNITS: ☐ METRIC ☐ IMPERIAL

OUTLET			LANE		TESTED LENGTHS			METHOD		INSP.	EW-12	COMMENTS
NO.	STATION	PIPE DIA.	DIR	SHLD	① DIR	OUTLET DIST.	TOTAL DIST.	CAMERA	PROBE	SATISF. Y / N	SATISF. Y / N	

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