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Drainable Pavement Systems
Instructor's Guide

Demonstration Project 87

Office of Engineering and
Office of Technology Applications
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Washington, D.C. 20590

TECHNOLOGY APPLICATIONS
Innovation Through Partnerships

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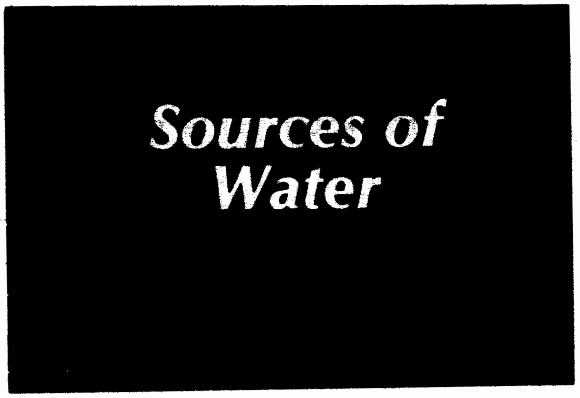
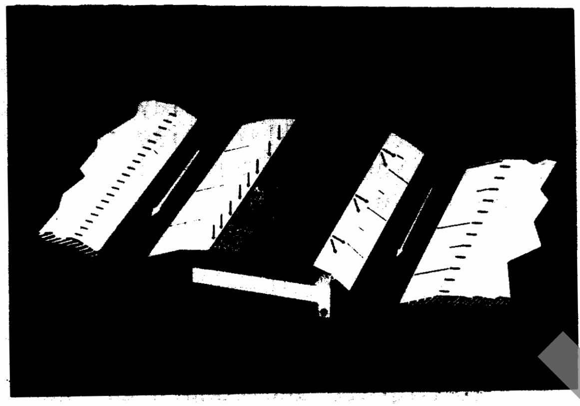
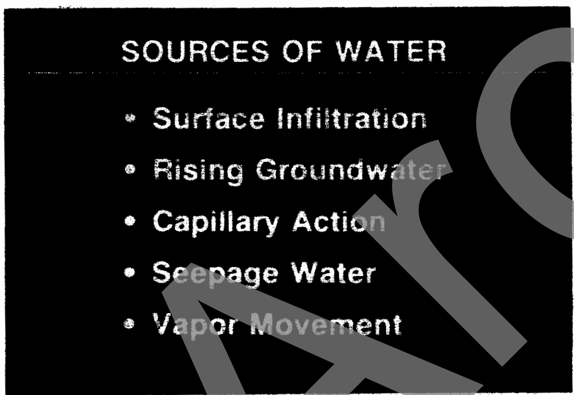


The purpose of this Demonstration Project is to provide rapid removal of water from the concrete pavement section.



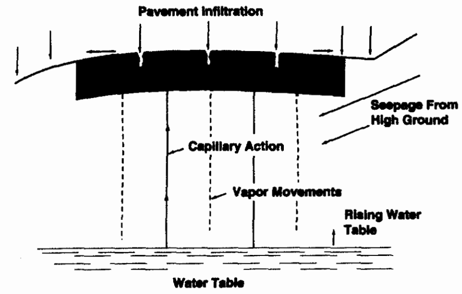
The purpose of drainable pavement systems is to remove water entering the pavement structure from cracks and joints in the concrete pavement.



There are many sources of water can enter the pavement structure and saturate the base. Sources of water include:

- Surface Infiltration
- Rising ground water
- Capillary action
- Seepage Water
- Vapor movement

SOURCE OF WATER



Rising Groundwater

Seasonal fluctuations of the water table can be a significant source of water.

Seepage Water

In cut sections where ditches are shallow, seepage of water from higher ground may be a significant problem. Or if water is sitting or ponding in ditches, then water can seep under the pavement section.

Capillary Action

Capillary Action can transport water well above the water table saturating the subgrade. Clay soils are potential problems with capillary rise in excess of 20 feet. This source of water is responsible for frost heave.

Vapor Movement

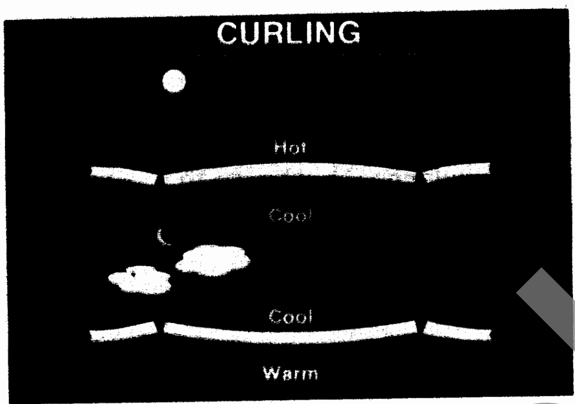
Temperature gradients can cause the water vapor, present in the air voids of the subgrade and pavement structure, to migrate and condense. Water vapor does not provide a significant volume of free water in the pavement structure.

It is important to investigate whether any of these sources are contributing to base saturation. If they are present you should contact your geotechnical engineer or reference the Highway Subdrainage Manual to address each individual source.

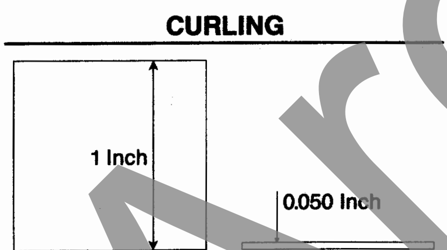
Remember, the number on source of water entering the concrete pavement structure is infiltation through joints and cracks. The intent of the design of the pavement drainage system we are recommending, is to provide rapid removal of water entering the pavement structure through cracks or joints in the concrete pavement.

Why did we initiate this Demonstration Project? Most engineers will agree that the most prevalent distresses in concrete pavements are faulting at joints, cracks in the pavement due to loss of support through base pumping. These distresses result from saturated erodible bases and heavy trucks loadings. Pumping, faulting and moisture distresses are not accounted for in most design procedures.

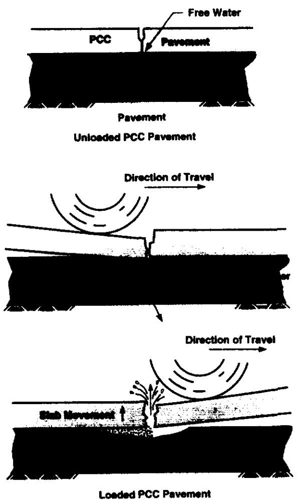
Pavement drainage systems are designed to prevent pumping by reducing the free water in the pavement structure. To review, let's talk about how these distresses start.



After the pavement slab has been placed, moisture change and temperature change cycles cause the slab to curl creating small voids under the pavement slab at the joints. The amount of curling is a function of base stiffness and slab length.

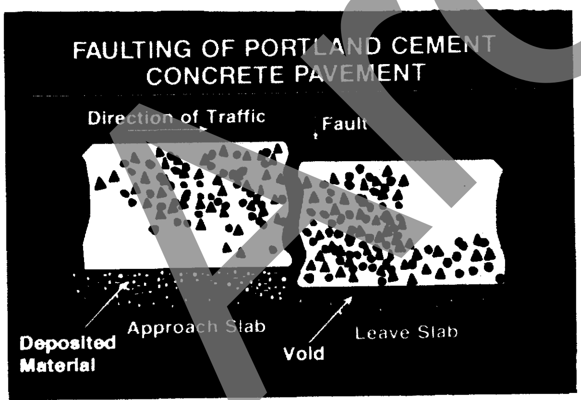


When we are talking about curling, the previous diagrams over exaggerated the amount of curling. We are talking about maybe 5 hundredths of an inch of a void in most cases. However, this is enough of a void that can lead to pavement distress.

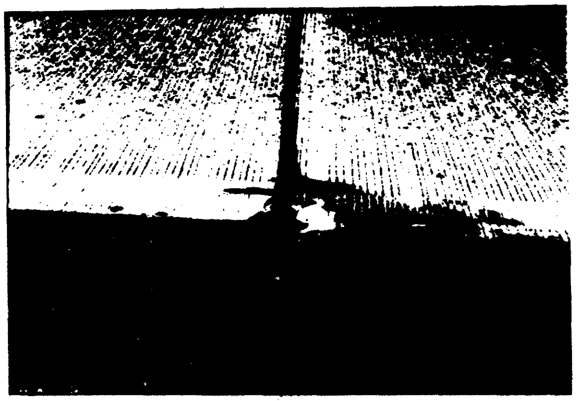


As pavement joints open up, water can enter the pavement structure and saturate the base. Once the base is saturated, free water will collect in the voids. Then as heavy loads approach the joint, the approach slab will deflect downward sending a pressure wave or water jet towards the leave slab. This begins the erosion of fines in the base course. As the wheel crosses the joint, the approach slab rebounds and the leave slab deflects downward, sending a pressure back underneath the approach slab. This water action carries fines which are finally deposited under the approach slab which raises its elevation. Once the voids under the approach slab are filled, excess moisture and fines are pumped through the joint or crack.

See the violent pumping action. Not all of the fines are deposited underneath the slab. Some of the fines are pumped through the pavement joint as this photo shows.



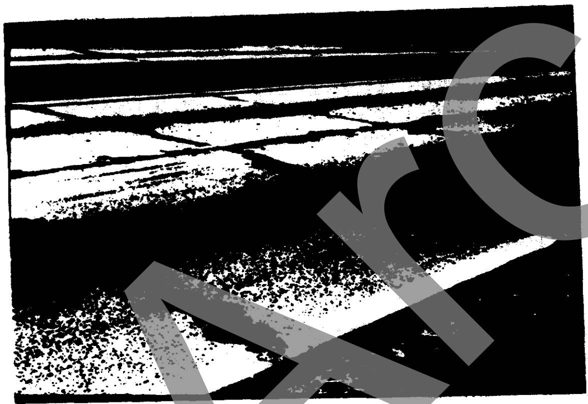
This pumping action, accumulating over time, will lead to a elevation difference between the two slabs. The elevation difference is known as faulting. Normally the approach slab is always higher that the leave slab.



This is an actual slide of faulting at the joint. The pencil is used to indicate the amount of faulting. Notice the shadow. You can also see pumping along the longitudinal joint. You can also see faulting driving down the road by looking in the rear view mirror.

Water can enter this joint. Dissimilar materials causes problems with joint separation. We recommend using tied concrete shoulders to maintain an adequate joint sealant reservoir. Another approach would be to use a widened lane to minimize edge loadings.

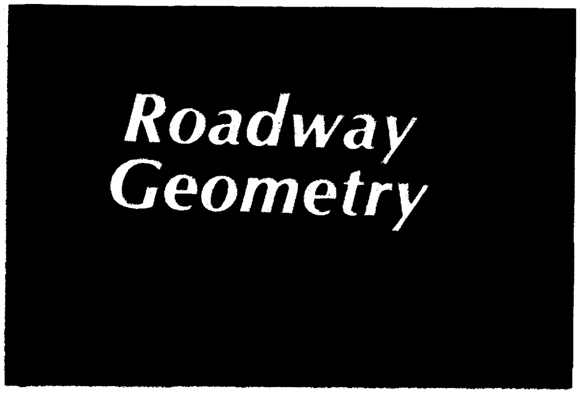
You can see cracks in the shoulder indicating loss of support. Over time this loss of support can lead to corner breaks in jointed concrete pavements or punchouts in continuously reinforced concrete pavements.



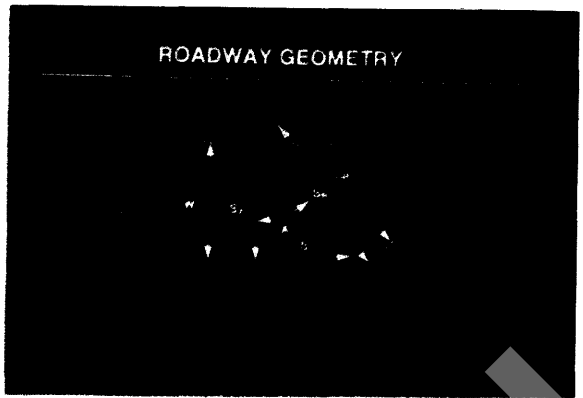
Failed Pavement Section

Pumping can lead to concrete pavement distresses such as faulting and pavement breaks due to loss of support. We have not found a base course material that when saturated will not lead to pumping eventually.

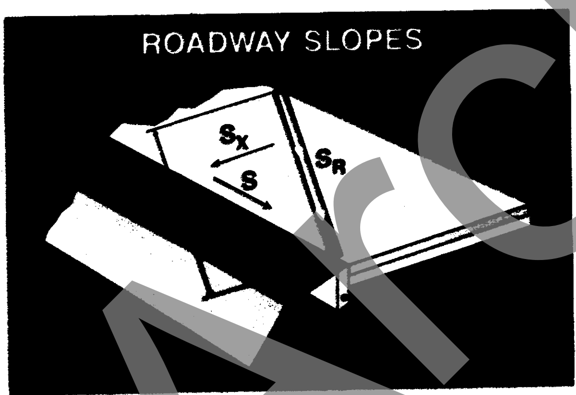
Therefore we are moving to pavement drainage systems to rapidly remove moisture from the pavement structure to eliminate pumping due to saturated base courses.



Roadway Geometrics plays a part in the design of a pavement drainage system. Most drainage formulas have slope as one of the input variables. What is the slope of the flow path of water through a permeable base?

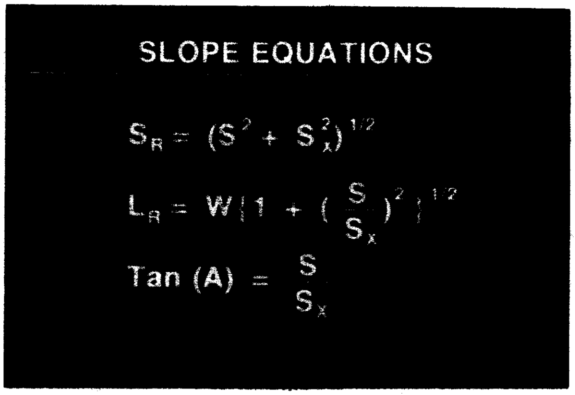


When you initially think about the length of the flow path, you initially assume that water will flow in the permeable base along the cross slope of the pavement. However, after sketching the pavement section you can see that you have to account for the longitudinal slope or profile grades of the roadway.



The roadway usually has a cross slope for surface drainage. The cross slope is shown as S_X. Not all of the roadways are flat, thus they will have a longitudinal grade, shown as S. When designing permeable base layers we must take into consideration the longitudinal slope. Combining the two slopes will give a true or resultant slope S_R. The water flow path L_R will follow the resultant slope.

S_x and S are used to be consistent with the nomenclature the hydraulic engineers use.



When the longitudinal slope is combined with the pavement cross slope, the resultant slope can be determined by this equation.

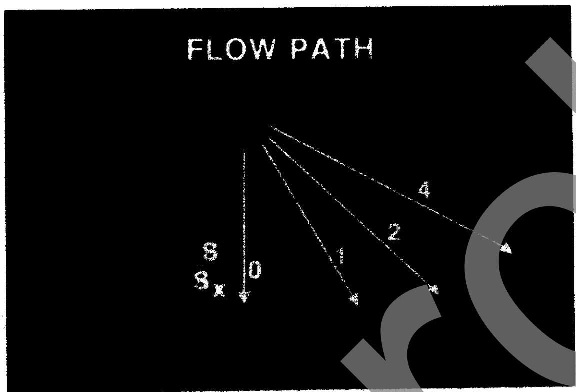
$S_R = (S^2 + S_x^2)^{1/2}$ where:
S_R = Resultant slope, ft/ft
S = Longitudinal slope, ft/ft
S_x = Cross slope, ft/ft

To determine the length of the flow path, you multiply the width of the base times the tangent of angle A which works out to this formula.

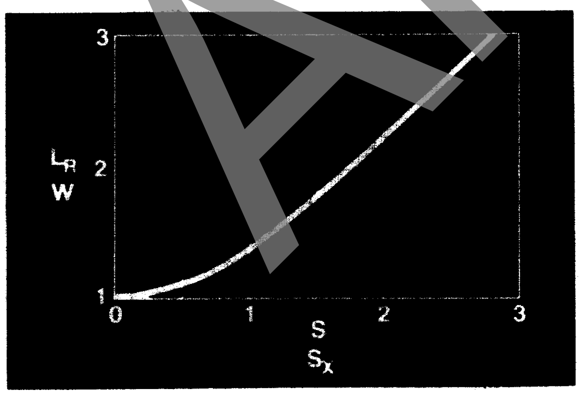
$L_R = W(1+(S/S_x)^2)^{1/2}$

Where:
L_R = Resultant length of base, ft
W = Width of permeable base, ft

The length of the flow path is never less than the width of the pavement.

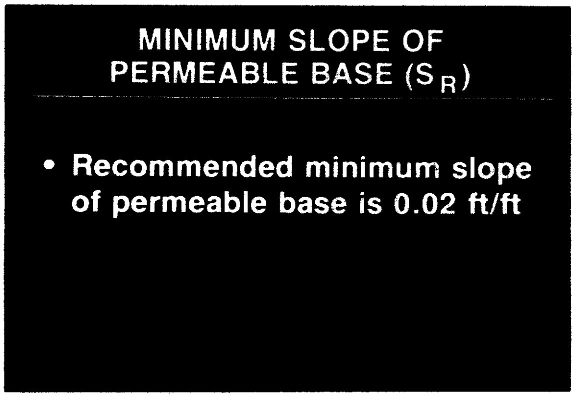


This is a graphical presentation of the relationship between longitudinal slope to the cross slope. As you can see, as the longitudinal slope increases, the flow path will move away from the cross slope or move towards S/S_x=4.



Graphical relationship between the resultant length/width ratio to the longitudinal slope/cross slope ratio.

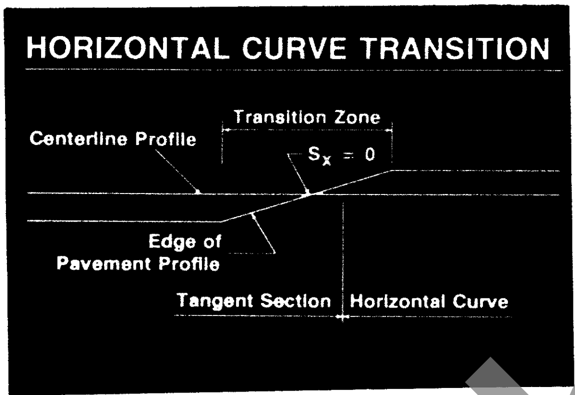
A 2 percent cross slope and a 2 percent longitudinal slope will result in a 1.4 multiplier. The point is that the resultant length will never be less than the width of the base.



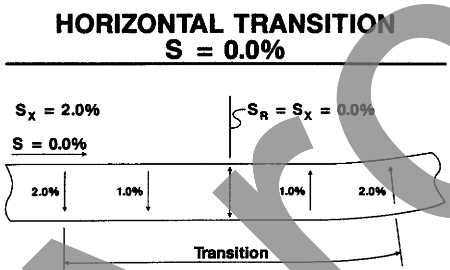
It is recommended that the minimum cross slope of the permeable base is 0.02 ft/ft. Remember that each time the roadway profile grade changes, the resultant slope has to be recalculated.

If the cross slope is set at 0.02 ft/ft, in most cases the minimum resultant slope requirement will be satisfied.

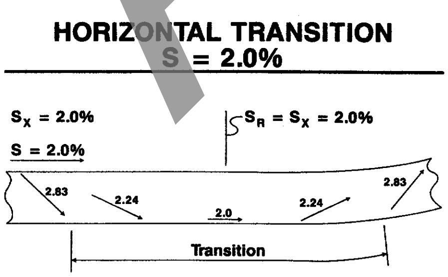
However, there are special cases that must be considered.



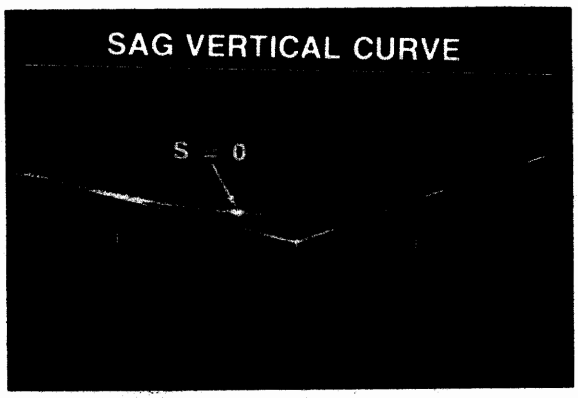
Any time one of the slope components is equal to zero, a potential drainage problem may exist. On horizontal curves, the cross section will go through a transition section as the superelevation is being developed. At one point in the transition area the cross slope will be equal to zero.



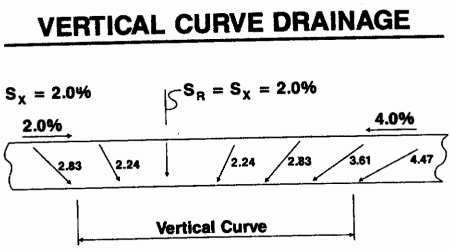
This is the worst case scenario. The longitudinal slope is equal to zero, and we are providing a superelevation transition for a horizontal curve. We have a potential problem when the cross slope is zero. At this point, water does not want to flow. This might be a good location to place a transverse drain. It should be noted that the minimum resultant slope of 0.02 ft/ft will not be met in the transition area.



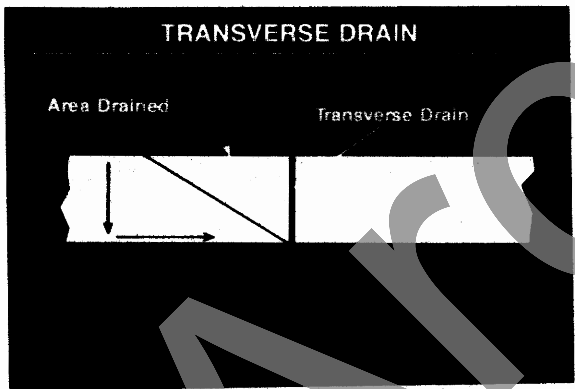
Another situation, the longitudinal slope is equal to 2 percent. In the horizontal transition, we get a reversal of flow. It is interesting to note that near the transition, water can start on the inner edge, move towards the outer edge, then at the transition change directions and exit at the inner edge. At this location, you want to have longitudinal edgedrains on both sides of the pavement.



On sag vertical curves the longitudinal slope will be equal to zero. This may be another situation for transverse drains.



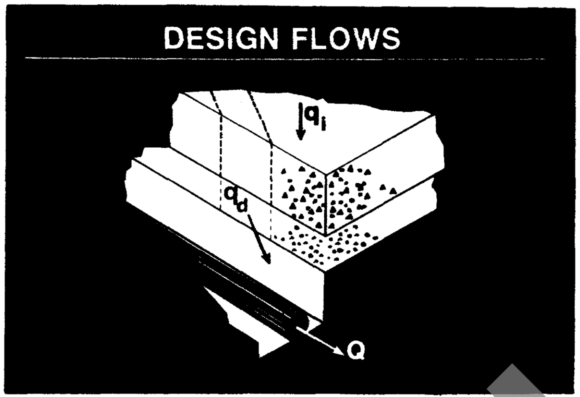
On sag vertical curves, you can see that the water is draining to the low point. You may wish to place a outlet pipe at this location.



This slide shows the area that will drained by a transverse drain. Transverse drains only drain a relatively small area.

This photo shows that sometimes the flow of water may not even follow the calculated flow path. This photo makes on wonder if the subsurface drainage is following the same path. It also show the importance of performing field surveys for pavement design instead of relying on strictly as-built information.

There are two types of hydraulic design philosophies that are used for pavement drainage systems. The first is to size the system for the water that can enter the pavement structure or pavement infiltration. The other approach is to assume that once water completely saturates the permeable base, water will not continue to enter the pavement structure and will run off to the shoulder. The permeable base is designed to remove a quantity of water is a time period. This is called Time to Drain. This concept is recommended in this Demonstration Project.

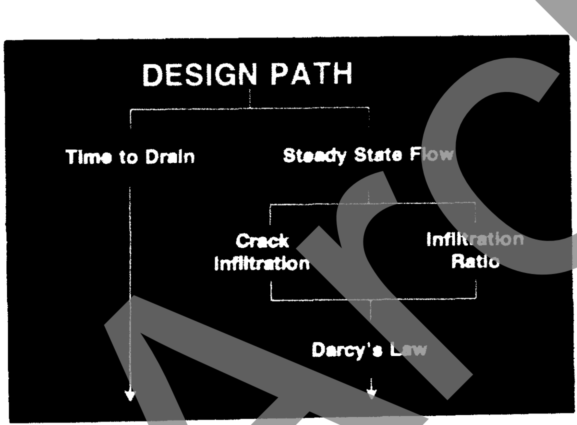


Before we proceed, it is appropriate to discuss the different flow terms in pavement drainage. These are:

q_i = Pavement Infiltration, in cf/day/sf of pavement.

q_d = Permeable base discharge rate, in cf/day/ ft of base.

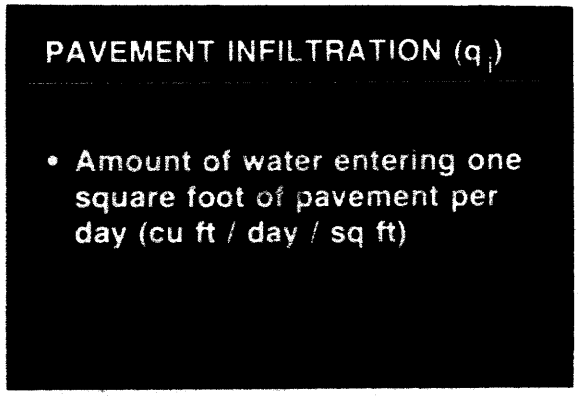
Q = Pipe flow, in cf/day.



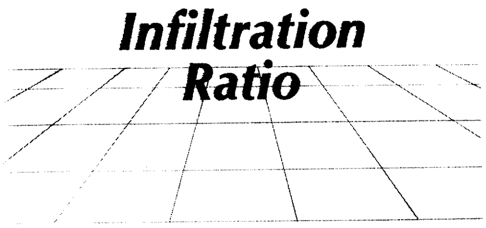
This slide shows the flow path of the two design procedures.

Past FHWA work has highlighted the steady state flow approach. In the Steady State flow method, the pavement infiltration is determined, by either Crack Infiltration or Infiltration ratio. Darcy's Law is used to determine the permeable discharge rate and the pipe flow. The permeable base and edgedrains are designed to handle these rates.

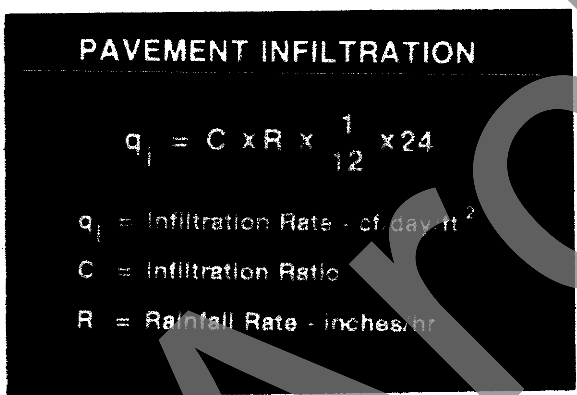
Limitations with the design approach is that there is a lack of information on the amount of water that infiltrates the pavement systems. We recommend Time to Drain. However, since some engineers still use the approach we will discuss it now.



Pavement Infiltration is the rate of the water entering on square foot of pavement. It can be determined by two methods.



The first approach to determining the rate of pavement infiltration is the Infiltration ratio method. Basically, we assume that a percentage of a storm rainfall enters the pavement structure through faulty joints or cracks.



Pavement infiltration is determined by the equation.

$q_i = 2CR$

q_i = pavement infiltration, cf/day/sf of pavement
C = infiltration ratio
R = Rainfall rate, inches/hr.

A design rainfall rate and the infiltration ratio have to be selected.

A design storm whose frequency and duration will provide adequate drainage must be selected. A design storm of 2 year frequency and 1 hour duration is recommended. The rainfall intensities under this design storm represent the average worst storm that occurs each year.

The rainfall rate can be selected from this map.

INFILTRATION RATIO

Asphalt Concrete Pavement	0.33 - 0.50
Portland Cement Concrete Pavement	0.50 - 0.67

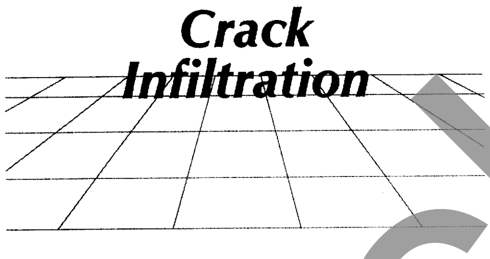
The second input is the infiltration ratio. It represents the portion of rainfall that enters the pavement through joints and cracks.

The following values have been used:

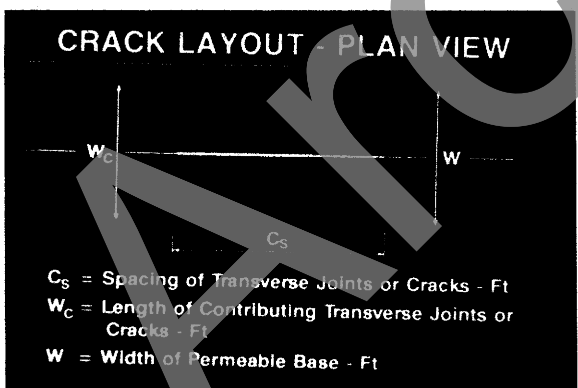
Asphalt concrete pavements - 0.33 to 0.5
Portland cement concrete pavements - 0.5 to 0.67

Since the range of these values is so wide, a value of 0.5 is recommended for use in design. You can begin to see why we like the Time to Drain concept.

Once the infiltration ratio and the rainfall rate are selected, multiplication will give you pavement infiltration to use in design.

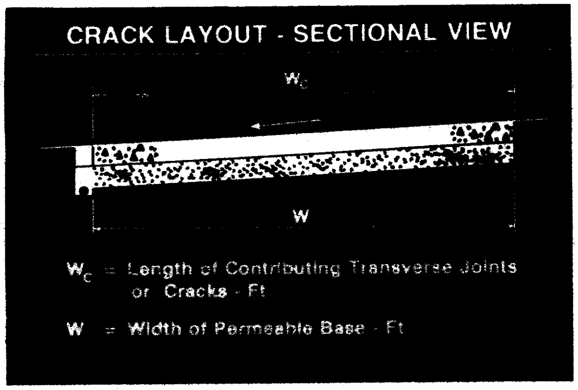


Another way to determine pavement infiltration is the Crack Infiltration Method. In this method, past research is used to determine a crack infiltration rate, then the number and length of cracks or joints that have water infiltrating are determined and the crack infiltration is applied to determine pavement infiltration.

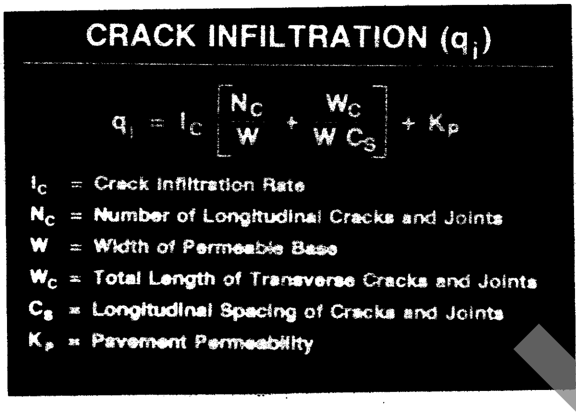


The first step is to determine the amount of cracks or joints contributing to water entering the pavement structure. For new or reconstructed pavements, we recommend that you consider that all of the joints are allowing water to enter. This would be a conservative approach.

In the plan view, the length of the transverse joint is divided by transverse joint spacings to get length of crack per square foot of pavement.



The length of contributing cracks and width of permeable base are shown in a sectional view. Usually the width of the contributing crack is set equal to the width of the permeable base.

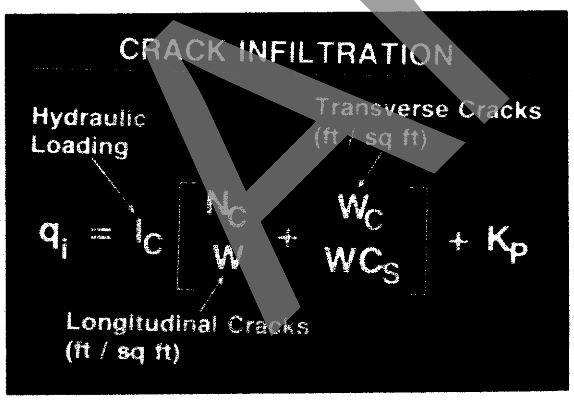


Crack infiltration can be determined by the equation:

$$q_i = I_c \left[\frac{N_c}{W} + \frac{W_c}{WC_s} \right] + k_p$$

q_i = Infiltration rate, cf/day/sf
I_c = Crack Infiltration rate, cf/day/ft of crack
N_c = Number of longitudinal cracks
W_c = Width of contributing transverse cracks, ft
C_s = Spacing of contributing transverse cracks, ft
W = Width of permeable base, ft
K_p = Pavement permeability, cf/day/sf

Since concrete is assumed to be impermeable, then $K_p = 0$



In the equation,

I_c is the hydraulic loading.

W_c/WC_s is the transverse crack length per square foot of pavement.

N_c/W is length of longitudinal cracks per square foot of pavement.

You can see with crack infiltration, we are making the assumption that all joints are not sealed and water is entering them. This can give you a high infiltration rate that can lead to a large thickness of the permeable base.

NUMBER OF LONGITUDINAL CRACKS (N_C)

$$N_C = N + 1$$

N = Number of Lanes

The number of longitudinal cracks is simply the number lane joints and shoulder lane joints. It is simply calculated by adding 1 to the number of contributing lanes.

For a crowned section this approach is very conservative because both lanes considered that the full amount of water entering this joint will flow in that direction. In reality, the only water entering the centerline joint would be rain that fell directly on the joint.

HYDRAULIC LOADING

I_C = 2.4 cf/day/ft

K_p = Pavement Permeability - cf/day/ft^2

The Highway Subdrainage Manual suggests using a crack infiltration rate of 2.4 cf/day/ ft of crack. It must be remembered that this rate is backed up by a limited amount of research. For this approach, each State should conduct research to verify this value.

For concrete pavements, the pavement permeability is considered zero.

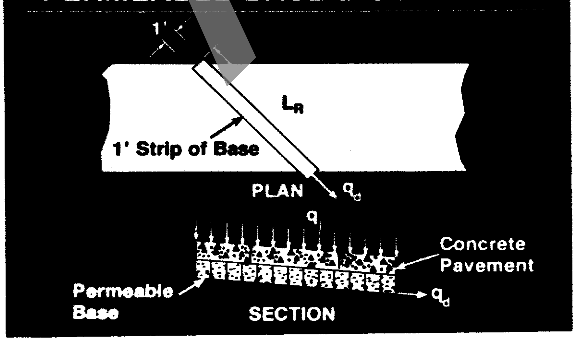
Pavement infiltration is calculated by inserting the values into the equation.

PERMEABLE BASE DISCHARGE RATE (q_d)

- Amount of water discharging from a 1 ft wide strip of permeable base (cu ft / day / ft)

Once pavement infiltration is determined, the permeable base discharge rate is calculated. Permeable base discharge rate is defined as the amount of water discharging from a 1 foot wide strip of permeable base. Its unit are cf/day/ft of base.

PERMEABLE BASE DISCHARGE



The elements that contribute to the permeable discharge rate are pavement infiltration and the Resultant length of the permeable base. The highlighted area represents the permeable base discharge rate. For one foot of base, $q_d = q_i*L_R$.

BASE DISCHARGE

$$q_d = q_i L_R$$

Where:

q_d = Base Discharge - cfd/ft
q_i = Pavement Infiltration - cfd/ft^2
L_R = Resultant Length - ft

Permeable base discharge rate can be determined by the equation

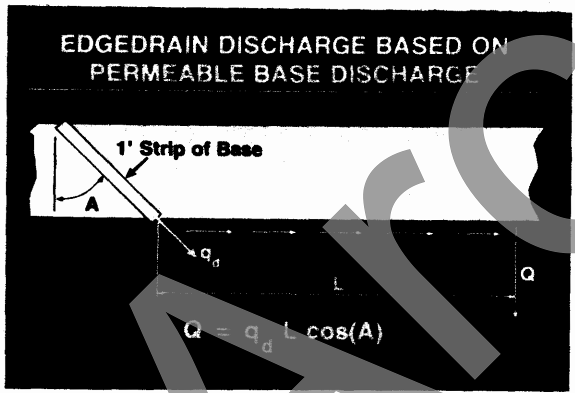
$q_d = q_i L_R$ = Resultant length of base, ft

q_d = Permeable base discharge rate, cf/day/ft of base
q_i = infiltration rate, cd/day/sf
L_R = Resultant length of base, ft

PIPE FLOW (Q)

- Amount of water flowing in edgedrain pipe (cu ft / day)

Edgedrain pipe flow is determined after calculating the permeable base discharge rate. Pipe flow is the rate of water flowing in an edgedrain pipe in cf/day.

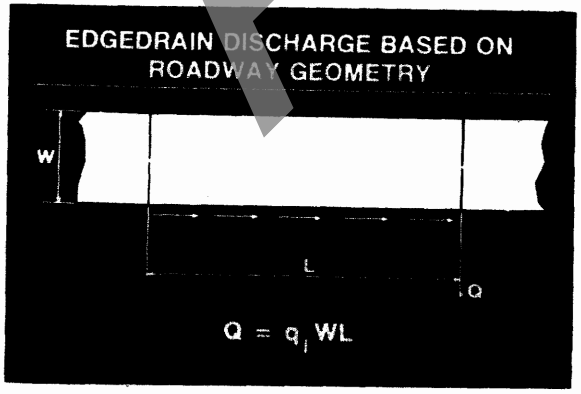


We determine the edgedrain pipe flow rate by the equation:

$Q = q_d L \cos(A)$

Q = pipe flow, cf/day
q_d = permeable discharge rate, cf/day/ft of base
L = longitudinal length of contributing roadway, ft. This length is the same as the outlet spacing.

A = Angle between a line perpendicular to the centerline of the roadway and the flow path in the permeable base.



Substituting the permeable base discharge equation for q_d, edgedrain discharge can be expressed as:

$Q = q_i L W$, where
L = outlet spacing, ft
W = width of contributing roadway, ft

Even though the flow path through the permeable base follows the resultant slope, the area in the parallelogram is the same as the shaded area in the rectangle.

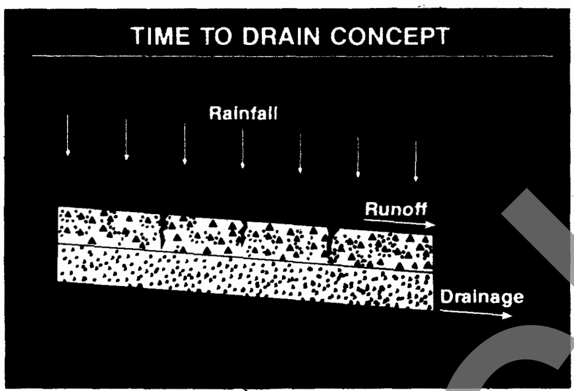
ANALYTICAL APPROACHES

- **Steady State Flow**
  - **Infiltration Ratio**
  - **Crack Infiltration**
- **Time to Drain**

To summarize, in the steady state process, the amount of water that enters the pavement structure is determined by the infiltration method or crack infiltration method. The permeable base thickness, the edgedrain pipe size, and outlet spacing are determined by Darcy's law and Manning's equation.

The Steady State method has its limitations. Basically, these limitations are the assumptions made to determine pavement infiltration. Either selecting the infiltration ratio or by assuming a crack infiltration rate. These methods may result in unrealistic base thicknesses.

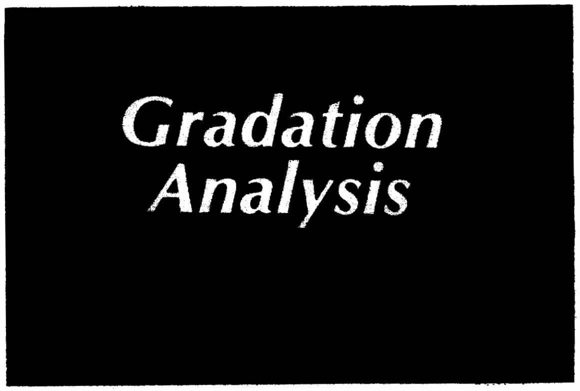
For this reason, we recommend the TIME TO DRAIN concept.



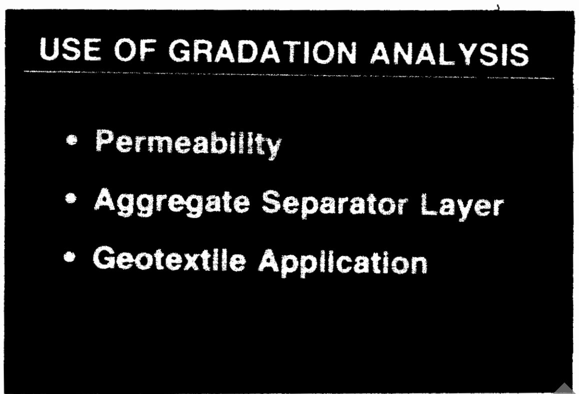
The time to drain approach.

It is the design approach we recommend in this workshop. Briefly, this approach assumes that water will enter the pavement structure until the permeable base is saturated, the excess water will then runoff the pavement surface. After the rainfall event, the base will drain to the edgedrain system.

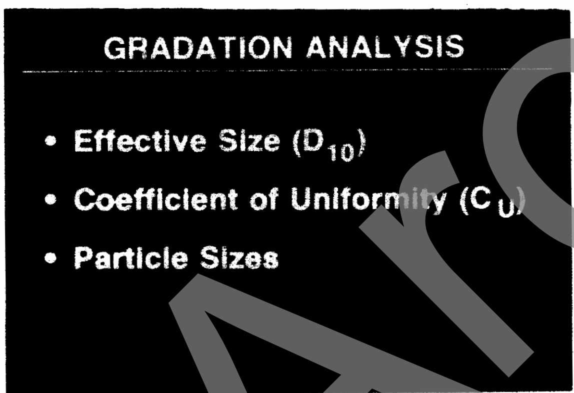
What engineers are concerned with is the time it takes the system to drain. Because of all the assumptions in the steady state flow, a lot of engineers use the time to drain approach. As you will see later, it is a more practical approach.



GRADATION ANALYSIS



Gradation analysis is an important tool that aides the engineer in evaluating a material. Gradation of a material can aid the engineer in the design of material permeability, aggregate separator layer design, and geotextile design.

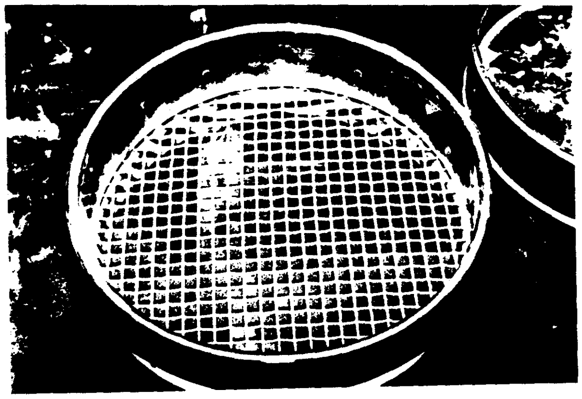


The elements in gradation analysis used in pavement drainage systems are:

- Effective Size
- Coefficient of Uniformity
- Particles Sizes

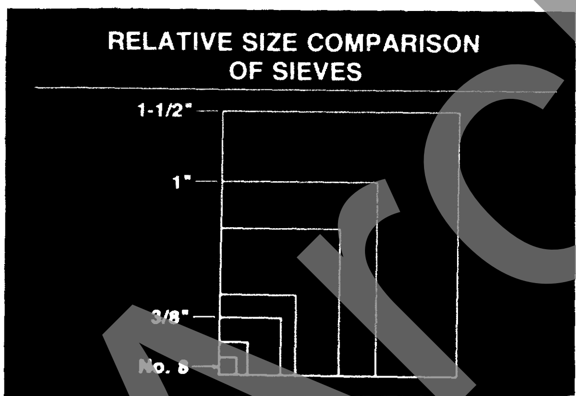
We will define these terms later.

Gradation analysis begins with sieving the material and separating individual particle sizes. This is a typical stacking of sieves.

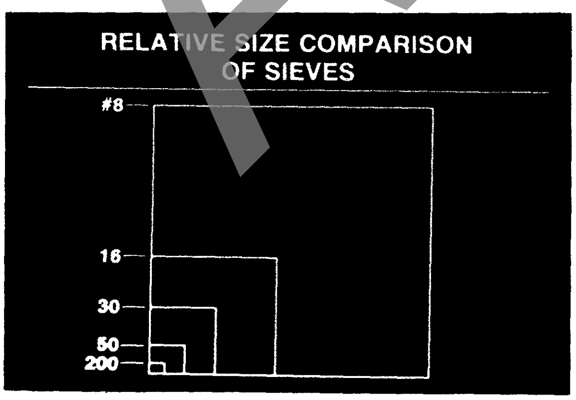


This is a #4 sieve. Each opening is 1/4 square inch.

This is the Number 200 sieve. We are interested in the amount of fines passing the number 200.



This is a graphical illustration showing the comparison of the different sieve sizes. The 1½ " to Number 8 sieves are shown.



The Number 8 sieve is blown up to show the relative size comparison to the number 200 sieve.

The 1½ sieve is 500 times the size of the number 200 sieve. We are talking about a rather large range of material sizes.

GRADATION

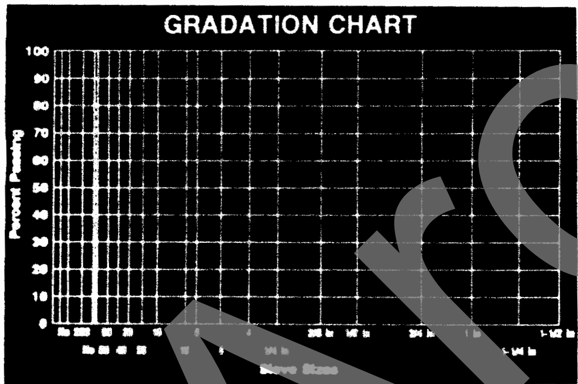
Sieve Size	Sieve Opening (mm)
1-1/2"	38.1
1"	25.0
3/4"	19.0
1/2"	12.5
3/8"	9.5
No. 4	4.75

Standard sieve sizes and opening sizes. One half nesting is recommended. 1½ inch through the number 4 sieve.

GRADATION (continued)

Sieve Size	Sieve Opening (mm)
No. 8	2.36
No. 16	1.18
No. 30	.60
No. 50	.30
No. 100	.15
No. 200	.075

The sieve openings for the number 8 through the number 200 sieve.

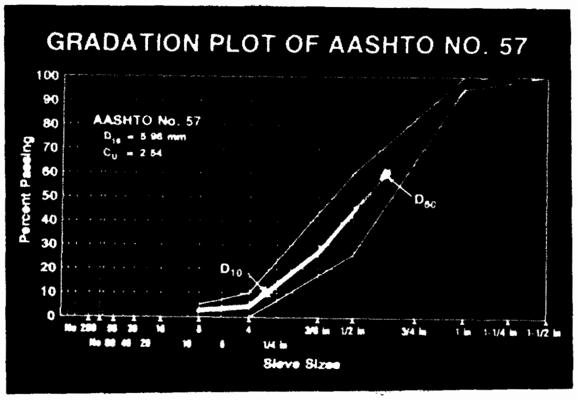


It is often convenient to plot gradations of materials on a gradation chart. This chart shown is the FHWA 0.45 power gradation chart.

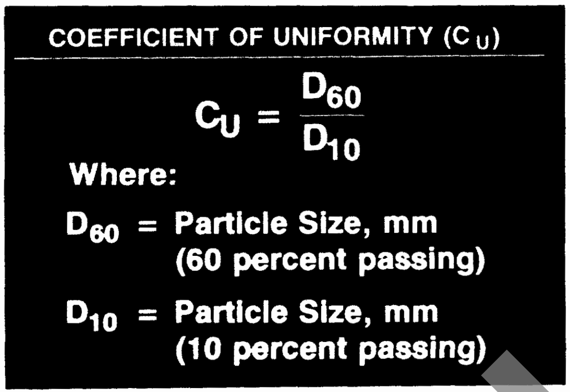
TREATED PERMEABLE BASE (AASHTO NO. 57)

Sieve Size	Percent Passing
1-1/2"	100
1"	95-100
1/2"	25-60
No. 4	0-10
No. 8	0-5

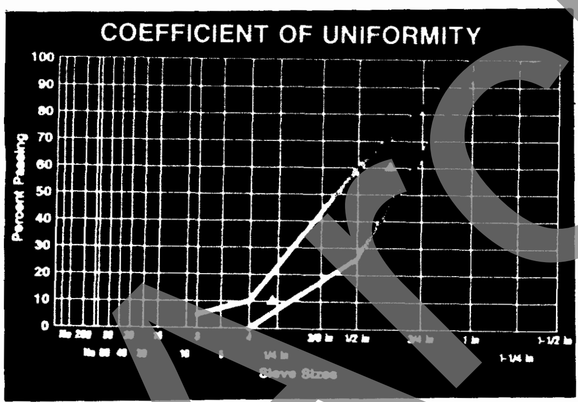
Lets take a look the gradation of the AASHTO Number 57 stone. It is considered the most permeable and open gradation used in highway construction.



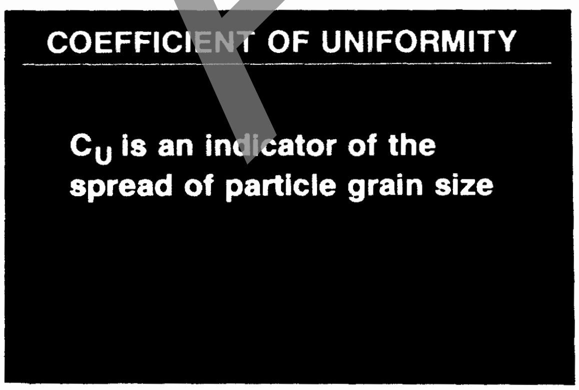
Lets plot the middle point of the gradation band of the AASHTO No. 57 stone on the gradation chart. Notice that we have plotted the points referred to D_{60} and D_{10}. These are the points where 10 percent of the material and 60 percent of the material are smaller than.



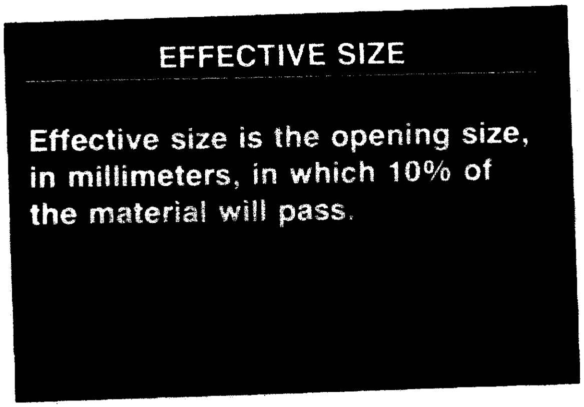
The coefficient of uniformity C_U is the ratio of the D_{60} particle size to the D_{10}.



The D_{10} and the D_{60} particle sizes of the mid-points of the AASHTO No. 57 gradation band are 5.98 mm and 15.18 mm respectively. You find this by finding 10 percent and 60 percent on the vertical scale and moving horizontal until you cross the gradation. Move down vertically and pick the particle size.

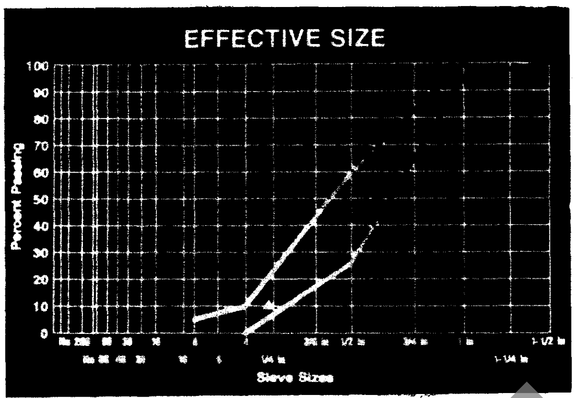


The coefficient of uniformity is an indicator of the spread of the particle grain size of a material. It is an indication of how dense graded the material is. It is also an indication of the material's permeability. Typical dense graded material will have a range of 40 to 50, while open graded material will have a low range coefficient of uniformity (2 to 6). If the coefficient of uniformity is less than 4, then the material may be unstable. Material of one particle size will have a coefficient of uniformity of 1.

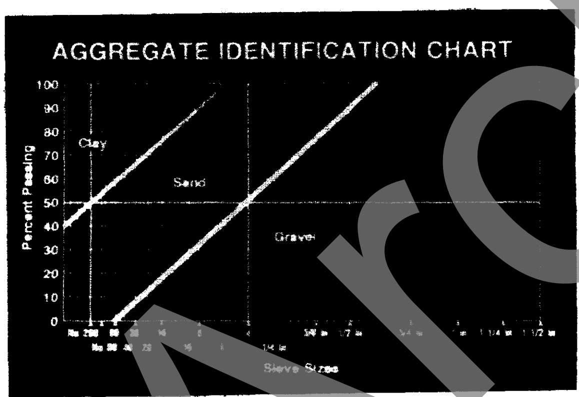


The effective size is the opening size, in millimeters, in which 10 percent of the material will pass.

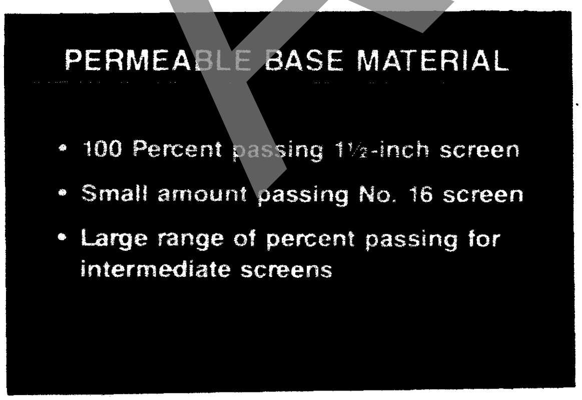
Effective size is the single best indicator of permeability.



Here is the effective size plotted on the gradation chart. The effective size is an indication of material permeability. The larger the effective size the larger the particle and the more open the material will be.



To get a qualitative feel for material being used and the gradation chart, the AASHTO soil classification system is superimposed on the chart. Clay is located in the upper left hand corner of the chart. To the right of the clay is the sand and to the right of the sand is the gravel. The basic trend you can see is that the gradation moves to the right of the chart, the material becomes more permeable.



Permeable base material has the following characteristics.

- 100 percent passing the 1½ inch screen.
- Small amount passing the number 16 sieve.
- Large range of percent passing for intermediate screens.

SAND MATERIAL

- 100 Percent passing 3/8- inch screen
- Greater than 50 percent passing No. 4 Screen
- Small amount passing No. 50 screen

Sand material has

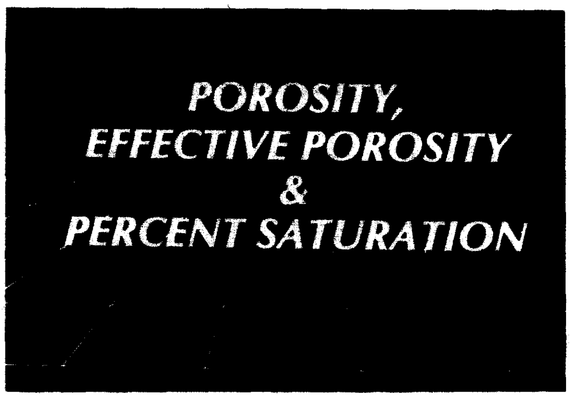
- 100 percent passing the 3/8 inch screen.
- Greater than 50 percent passing the No. 4 screen
- Small amount passing the No. 50 screen.

DGAB MATERIAL

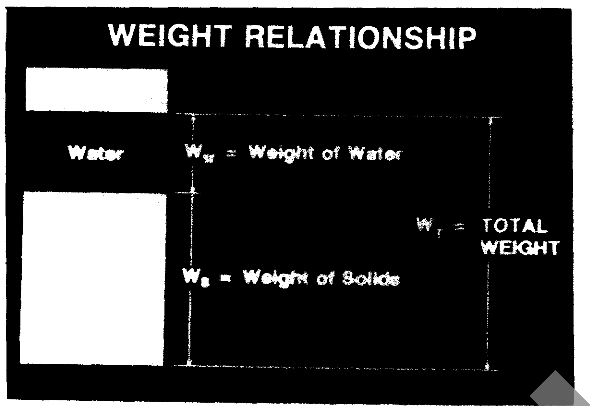
- 100 Percent passing 1½- inch screen
- 5 - 12 Percent passing No. 200 screen
- C_U between 20 and 50

Dense graded base material has

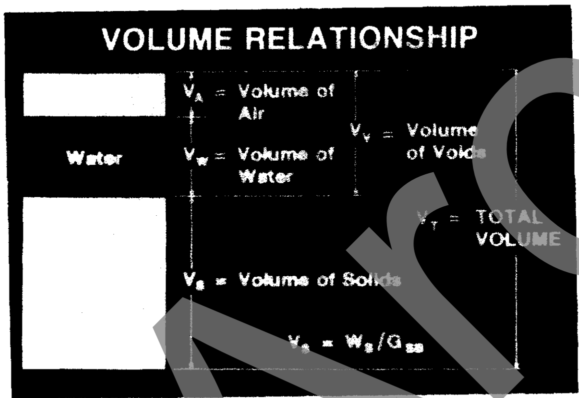
- 100 percent passing the 1½ screen.
- 5 - 12 percent passing the No. 200 screen.
- Coefficient of Uniformity between 20 and 50.



Material properties used in the Time to Drain Concept are: Porosity, Effective Porosity and Percent Saturation. These parameters are used to indicate an aggregate material's ability to store and give up water.

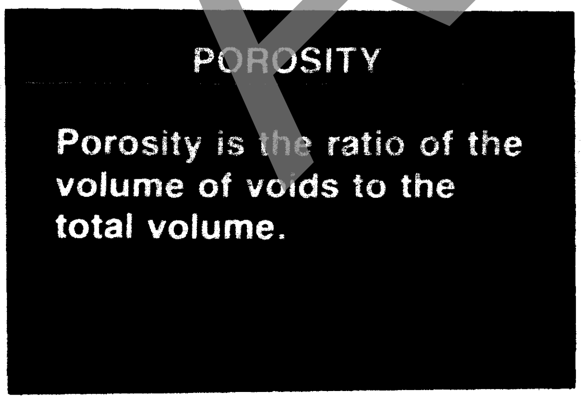


Before defining these terms, we need to go back and look at the phase diagram of a soil or an aggregate material. Here is the weight relationship. The total weight of the material is the weight of the solids plus the weight of the water. The air in a material does not have a weight.



The total volume of the material is the volume of air plus the volume of water plus the volume of the solids. The volume of air and the volume of water in the material makes up the volume of voids in the material. These volumes and weights are used in the previously mentioned terms.

Volume of the solids is determined by the weight of the solids divided by its bulk specific gravity.



Porosity is the ratio of the volume of voids in an aggregate or soil to the total volume. The porosity of a base material represents the maximum volume of water that can be stored per unit volume of that material.

POROSITY (N)

$$N = \frac{V_V}{V_T}$$

Where:

V_V = Volume of Voids

V_T = Total Volume

Porosity is expressed by the following equation

$$N = \frac{V_V}{V_T}$$

N = Porosity of soil sample
V_V = Volume of voids in a soil sample
V_T = Total volume of solid sample

POROSITY SUBSTITUTION

$$N = \frac{V_V}{V_T}$$

$$N = V_V$$

$$V_V = N$$

If the total volume is an unit volume (V_T = 1.0), then the porosity becomes numerically equal to the volume of voids ($N = V_V$).

Derivation of Porosity Equation

- Derivation of Porosity Equation

VOLUME RELATIONSHIP

$$V_T = V_V + V_S$$

$$V_V = V_T - V_S$$

We know that total volume equals volume of voids plus the volume of the solids ($V_T = V_V + V_S$).

Solving for volume of voids, we would subtract the volume of solids from the total volume ($V_V = V_T - V_S$).

POROSITY RELATIONSHIP

$$\frac{V_V}{V_T} = 1 - \left(\frac{V_S}{V_T}\right)$$

$$N = 1 - V_S$$

For a unit volume, then porosity would equal the total volume minus the volume of the solids ($N = V_V = V_T - V_S$).

For volumes other than unit volumes, we would divide the N equation by the total volume.

$$N = \frac{V_V}{V_T} = \frac{V_T}{V_T} - \frac{V_S}{V_T}$$

VOLUME OF SOLIDS (V_S)

$$V_S = \frac{\gamma_d}{62.4\ G_{SB}}$$

Where:

γ_d = Unit Dry Weight - lbs/ft ^{3}

G_{SB} = Specific Bulk Gravity - 2.70

The volume of solids is determined by dividing the dry unit weight γ_d by the product of the unit weight of water by the Bulk specific gravity G_{sb} of the aggregate or soil.

POROSITY (N)

$$N = 1 - \left(\frac{\gamma_d}{62.4\ G_{SB}}\right)$$

Where:

γ_d = Unit Dry Density - lbs/ft ^{3}

G_{SB} = Specific Gravity - 2.70

Substituting for volume of solids, the porosity equation can now be expressed by the equation

$$N = 1 - \frac{\gamma_d}{62.4G}$$

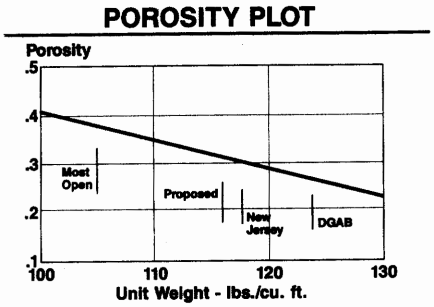
N = Porosity
γ_d = Unit dry density, lb/cf
G = Specific gravity, 2.70

OREGON REPORT

	Unit Weight lbs./cu. ft.	Porosity
Most Open	105.0	.376
Proposed	115.9	.312
New Jersey	117.6	.302
DGAB	123.6	.266

A report by the Oregon Department of Transportation discussed the unit weight and porosity of different materials.

As the porosity increases the unit weight of the material decreases. Porosity is directly related to voids. As the porosity increases, the volume of voids increases. As the void space increases, the unit weight of the aggregate must decrease. This makes sense.

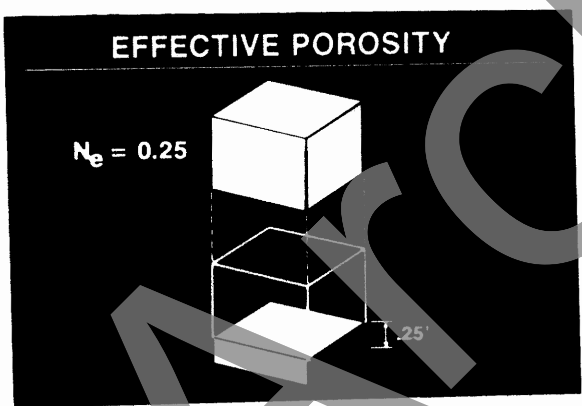


Relationship of porosity by unit weight shown graphically.

EFFECTIVE POROSITY

Effective Porosity is the ratio of the volume of water that drains to the total volume.

The effective porosity is the ratio of the volume of water that drains under gravity from the soil to the total volume of the sample. It is a measure of the amount of water that can be drained from a soil.



Effective porosity is a measure of how strongly a soil will hold water when a saturated sample is allowed to drain under the influence of gravity.

A permeable base will fill up with water and start to drain immediately. After the rainfall event, most of the water will drain. However, the material will not completely drain and will retain a certain moisture content. The capacity of the permeable base is related to the amount of water that will drain. We can not assume that capacity to be the total volume of voids. So we try to determine the amount of water that drains under gravity.

EFFECTIVE POROSITY (N_e)

$$N_e = \frac{\text{Volume of Water Drained}}{\text{Total Volume}}$$

Effective porosity is the volume of water drained from a sample divided by the total volume of that sample.

Effective porosity is used in the Time to Drain calculations since it represents the maximum amount of water that can be drained from a permeable base.

EFFECTIVE POROSITY (N_e)

$N_e = (N) \times (\text{Water Loss})$

If we can determine the water loss of a material and we know the material's porosity (volume of voids to total volume) we can determine the effective porosity by multiplying water loss by porosity.

Amount of Fines	< 2.5% Fines			5% Fines			10% Fines		
Type of Fines	Filler	Silt	Clay	Filler	Silt	Clay	Filler	Silt	Clay
Gravel	70	60	40	60	40	20	40	30	10
Sand	57	50	35	50	35	15	25	18	8

- Gravel, 0% fines, 75% greater than #4: 80% water loss
- Sand, 0% fines, well graded: 65% water loss
- Gap graded material will follow the predominant size

This table gives guidance for selecting a water loss value for Gravel and Sand with different fines content and types.

WATER LOSS

- Gravel 80%
  - 0% Fines
  - 75% Greater than #4
- Sand 65%
  - 0% Fines
  - Well Graded
- Gap Graded
  - Predominate Size Controls

Water loss for gravel with no fines and 75 percent retained on the No. 4 sieve would be 80 percent.

Water loss for a clean, well graded sand with no fines would be 65 percent.

For gap graded material the predominate size will control water loss.

DRAINED WATER

Drained Water $= N_e \times U$

U = Percent Drained

N_e = Effective Porosity

Now lets say you want to determine the volume of water drained if we drained 50 percent of the water from the permeable base.

Water drained would be the percent drained (we want to know 50 percent) times the effective porosity (the amount of water that can be drained from the permeable base).

VOLUME OF WATER (V_W)

$$V_W = V_V - \text{Drained Water}$$

$$V_W = V_V - (N_e \times U)$$

The volume of water left in the permeable base would be determined by subtracting the water drained from the volume of voids. In an equation this would be:

$$V_W = V_V - (N_e * U)$$

Volume of water equals the volume of voids minus the product of effective porosity and percent drained.

PERCENT SATURATION (S)

$$S = \left(\frac{V_W}{V_V}\right) \times 100$$

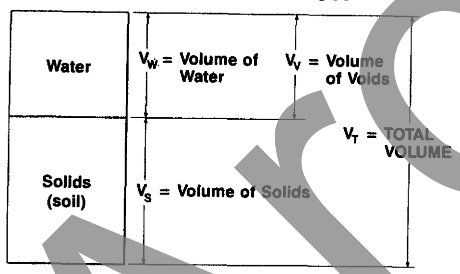
Where:

V_W = Volume of Water

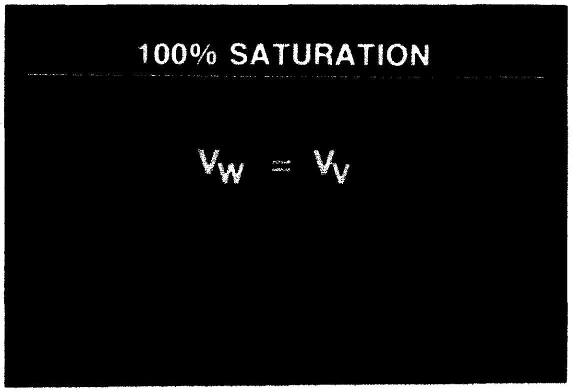
V_V = Volume of Voids

The final term is Percent Saturation. Percent Saturation is determined by dividing the volume of water by the volume of voids, and to express as a percentage multiplied by 100.

100% SATURATION



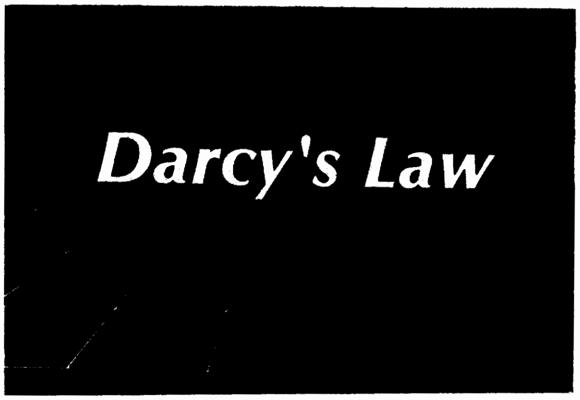
If we had a material that was 100 percent saturated, the volume of the voids would be completely filled with water.



For 100 percent saturation, the volume of water would be equal to the volume of the voids.

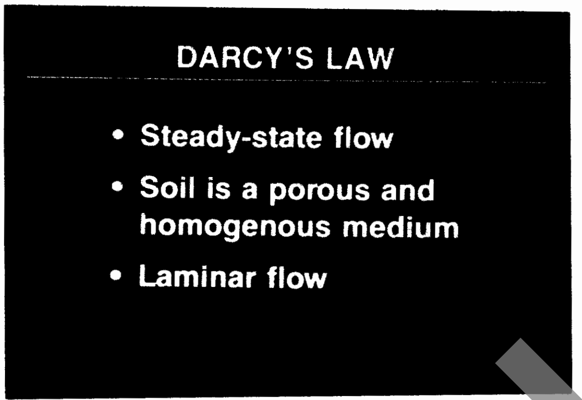
To summarize the relationship of porosity, effective porosity and saturation. Assume a material is 100 percent saturated. All of the voids in the material are completely filled. Assuming the material could drain all of the water from the voids, the volume of water drained would be equal to the porosity of the material. However, none of the materials used in highway construction can be completely drained by gravity and will retain a certain moisture content. Thus we can not use porosity to calculate the volume of water drained. Instead, the volume of water drained is the volume of the voids minus the volume of water retained. This relationship is effective porosity.

Effective porosity then is the maximum amount of water that can be drained from a material by gravity. Effective porosity will be used in the Time to Drain calculations.



Darcy's Law

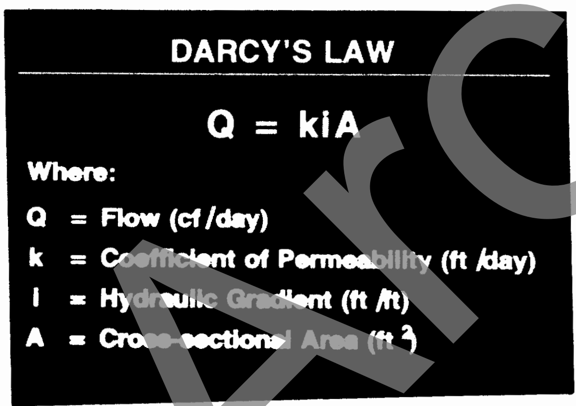
Darcy's law has been used since 1856 to define flow conditions in a soil.



This law is based on a number of assumptions. The major assumptions are:

1. Steady state flow.
2. Soil is a porous and homogenous medium.
3. Laminar flow.

These assumptions may not exist in actual practice. Laminar flow is smooth flow in which the flow stream lines are uniform. Some of the open permeable bases (No. 57 & 67 stones) will not meet Laminar flow condition. However, if K is determined by a laboratory test, we use Darcy's Law.



The discharge of a base is calculated using Darcy's law.

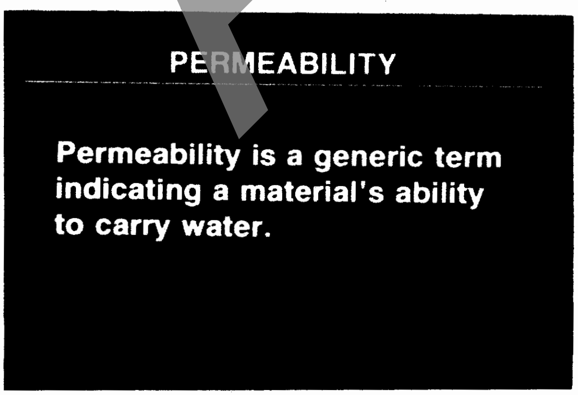
$Q = k\ i\ A$

Q = Flow capacity of the base, cf/day

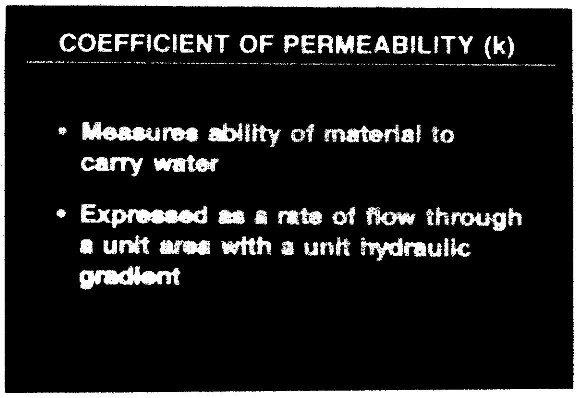
k = Coefficient of permeability, ft/day

i = Slope of hydraulic gradient, ft/ft

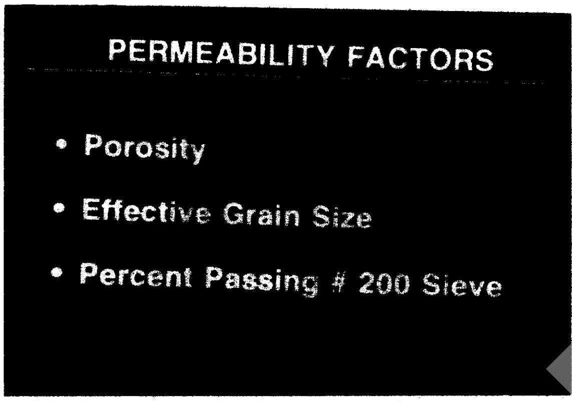
A = Cross sectional area of flow, sf



Permeability is a generic term used to indicate the capability of a soil to carry water.

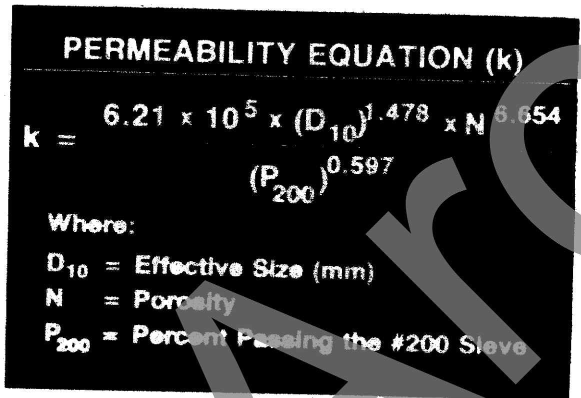


Coefficient of permeability is the flow rate through an unit area with a unit hydraulic gradient. It is the indicator of the quality of the material to carry water. The coefficient of permeability is the standard measure that engineers use to compare the flow capabilities of different materials. When Engineers use permeability as a term, they are really referring to coefficient of permeability.



The following material properties effect the permeability of a base.

1. Effective Size (D_{10}) - as the effective size increases, the base will become more permeable.
2. Porosity (N) - as the porosity increases, the base will become more permeable.
3. Percent fines (P_{200}) - as the percent fine increases, the base will become less permeable.

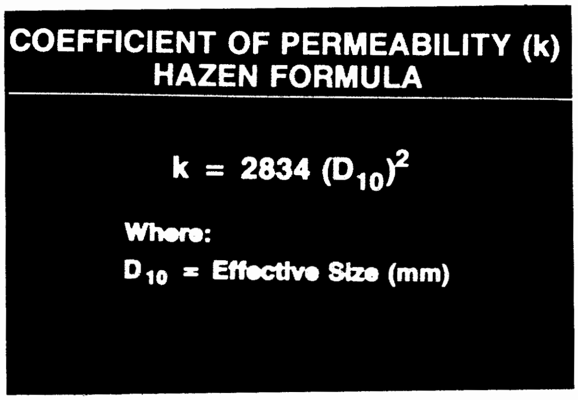


These three factors make up a design equation for calculating the coefficient of permeability used in the Highway Subdrainage Design Manual.

K = Coefficient of permeability, ft/day
D_{10} = Effective size, mm
N = Porosity of material
P_{200} = Percent of fines - percent passing the number 200 sieve.

This is the old equation that was used for subdrainage design. Most engineers no longer use this equation because:

1. Equation is too complex.
2. Most importantly, many engineers have had trouble when calculated coefficient of permeability results are compared with laboratory results of a sample.



Some engineers prefer to use Hazen's approximate formula for determining the coefficient of permeability. This equation is
$k = C\ (D_{10})^2$.

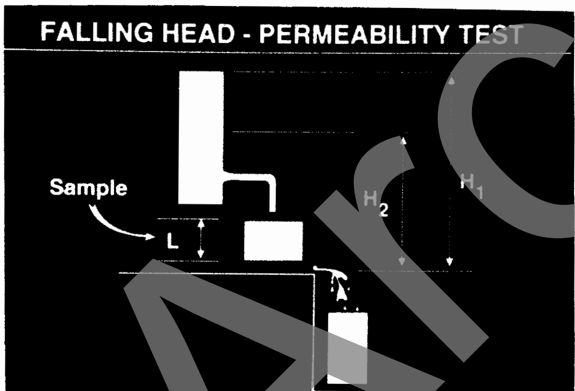
k = Coefficient of permeability, cm/sec
C = Coefficient - usually between 80 and 120
D_{10} = Effective size of material, cm

Using a C=100 and changing units of k, to ft/day, and D_{10}, to mm, the equation can be rewritten as follows.

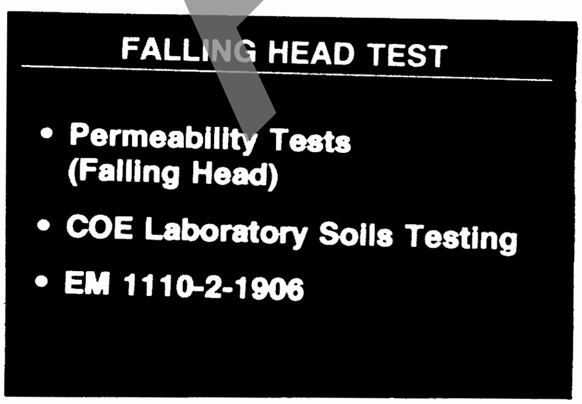
$k = 2834(D_{10})^2$

This equation has its limitations. It can be used when the coefficient of uniformity is less than 5 and when $0.1 < D_{10} < 3.0$ mm.

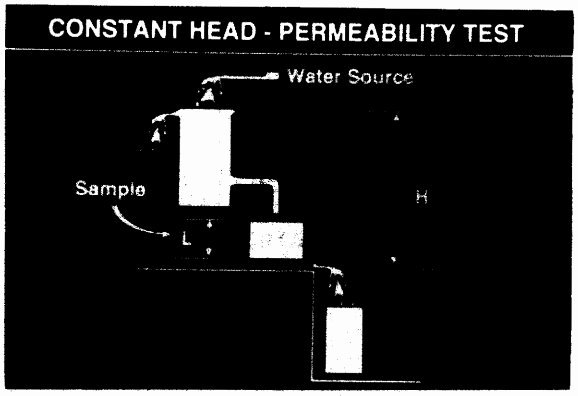
This equation will give a large variation in the coefficient of permeability from 28.34 to 25,500 ft/day. The highest that we measured in our laboratory was 7000 feet per day for a No. 57 stone. Therefore, it is therefore recommended that the coefficient of permeability be tested and evaluated in the laboratory.



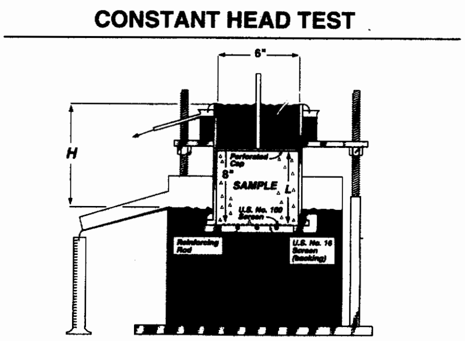
In the falling head permeability test, a known height of water (H_1) is placed over the permeable base material. A drain is opened and the water is allowed to flow through the base. The water level drops to a predetermined level (H_2). The time the water drops from H_1 to H_2 is kept. These are inputs to determine the coefficient of permeability.



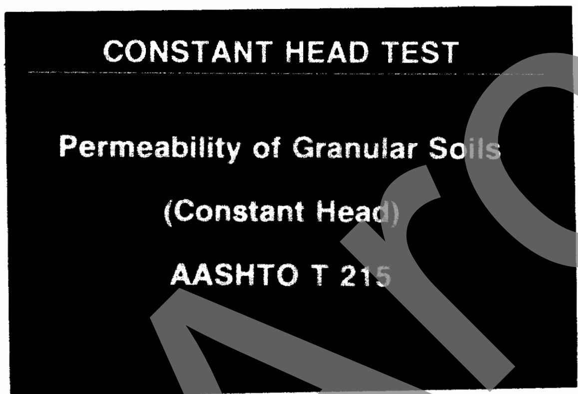
The falling head permeability test should be performed in accordance with The U.S. Army Corps of Engineers, <u>Engineering Manual, Soils Engineering Manual</u> EM 1110-2-1906.



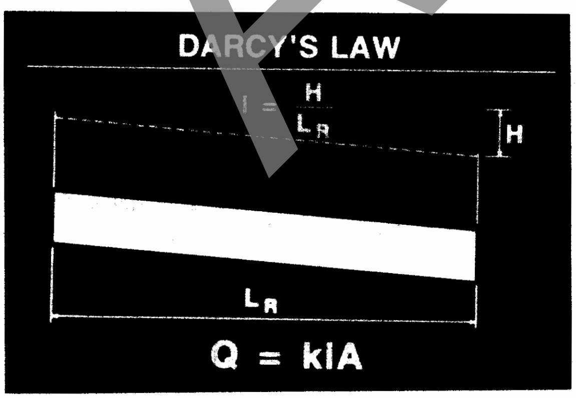
In the constant head permeability test, a known water height is kept constant as the output flow is measured. Darcy's Law is used to determine the coefficient of permeability.



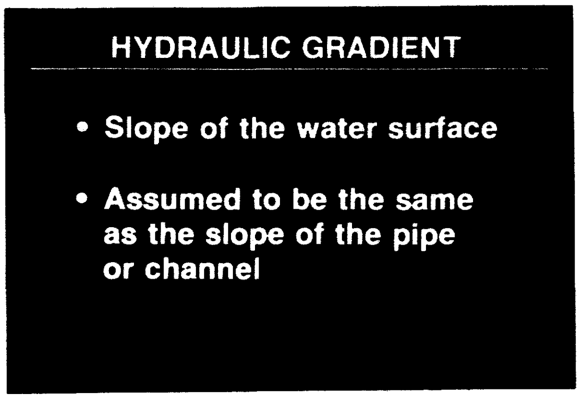
CALTRANS constant head test



The constant head permeability test is performed in accordance with AASHTO T 215, Permeability of Granular Soils

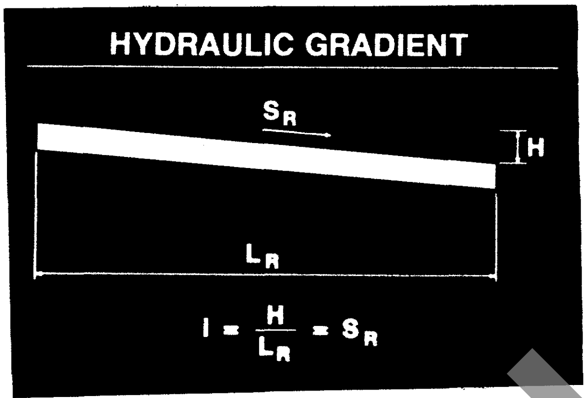


The hydraulic gradient is the slope of the water surface, difference in elevation of the water over a specified length. In both the falling head and constant head permeability tests, the hydraulic gradient is equal to 1.

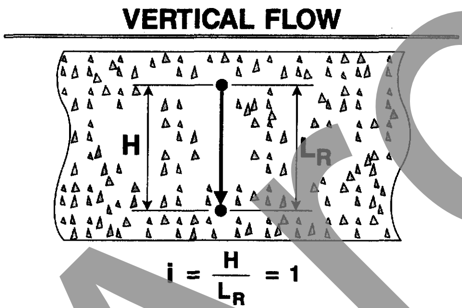


The hydraulic gradient is the slope of the water surface.

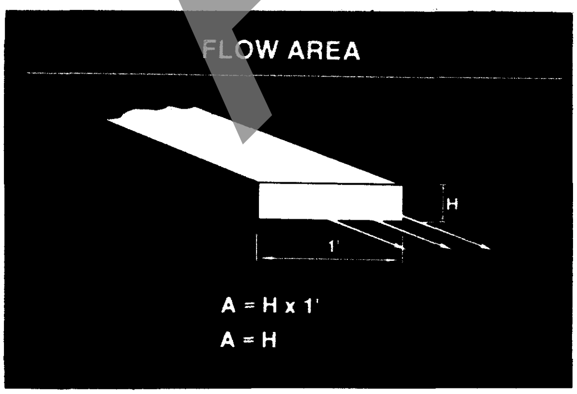
For storm drainage design, the hydraulic gradient is usually assumed to by the same as the slope of the pipe or the slope of the drainage channel



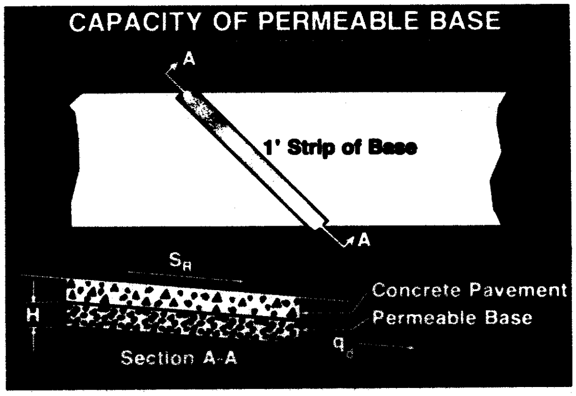
For permeable bases, the hydraulic gradient is equal to the resultant slope of the roadway. Remember that the longitudinal grade of the roadway and the cross slope of the pavement are combined to make up the resultant slope.



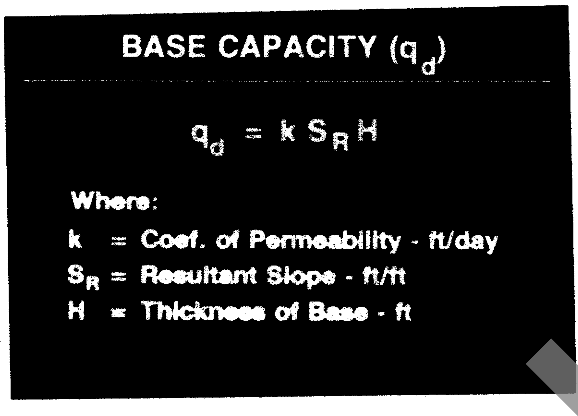
For vertical flow, the hydraulic gradient (i) would be equal to 1. The flow path (L_R) is equal to the thickness of the base (H).



Usually a 1 foot width of the permeable base is used for design purposes. We are going to determine the base discharge rate which is cf/day/ft. The flow area for the 1 foot width of permeable base would be equal to 1 foot times the thickness of the base in feet. Simplified the flow area for design is equal to the thickness of the base in feet.

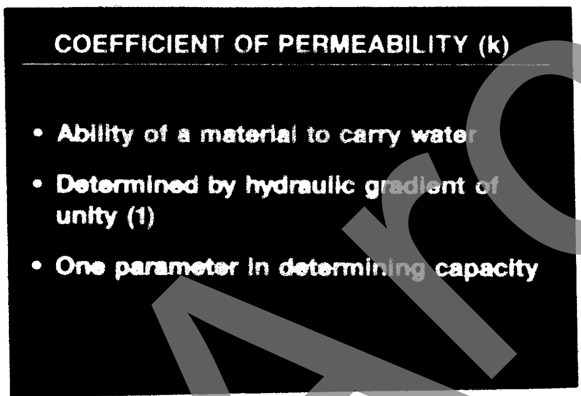


To determine the base discharge rate, we know the flow area is equal to the thickness and the slope of the permeable is equal to the resultant slope of the roadway. The third component is the coefficient of permeability of the base material.

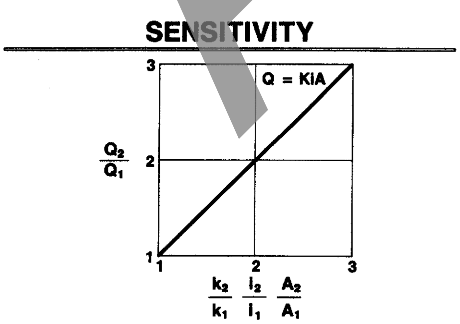


Remembering Darcy's law, Q = k i A, the base discharge can be determined by using the coefficient of permeability determined by lab test, substituting the resultant slope S_R for the hydraulic gradient, i, and multiplying these factors by a cross sectional flow area. For a one foot width of base,

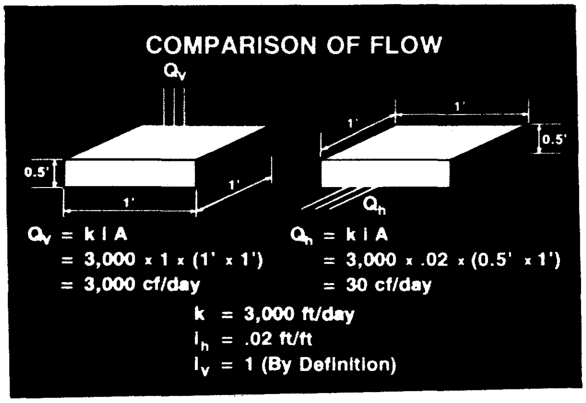
$q_d = k S_R H$
k= coefficient of permeability, ft/day
S_R = resultant slope ft/ft
H = thickness of base, ft
q_d = permeable discharge rate, cf/day/ft of base



The coefficient of permeability of a base material is the ability of that material to carry water. It is determined in the laboratory using a hydraulic gradient of 1. The coefficient of permeability is only one parameter used to determined the water flow of a material.



Equation sensitivity. Basically, this graph shows that if any one input into the flow equation is doubled, the flow will also double.



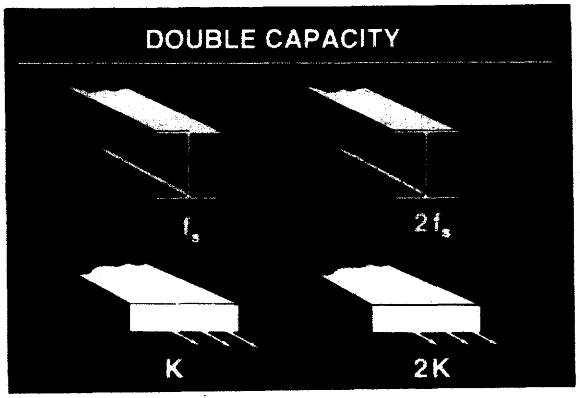
To aid in the understanding of the coefficient of permeability and Darcy's equation, I want to illustrate the comparison of vertical and horizontal flow for a 1 foot wide by 1 foot long by 0.5 foot thick base. Assume the coefficient of permeability for the base is 3000 feet/day.

For vertical flow:
$q_v = k\ i\ A$
k = 3000 ft/day
A = 1 ft x 1 ft = 1 sf, the flow is vertical therefore the flow is going through the 1 foot length by the 1 foot width cross section.
i = for vertical flow = 1 ft/ft
Therefore the vertical flow would be equal to 3000 cf/day.

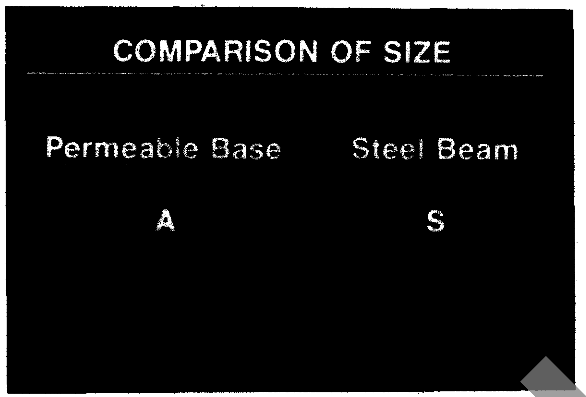
For horizontal flow, assume a pavement with a cross slope of 0.02 ft/ft.
$q_h = k\ i\ A$
k = 3000 ft/day
A= 0.5 sf, the flow is going through the 1 foot length by the 0.5 foot thick base cross section.
i = 0.02 ft/ft
Therefore, horizontal flow would be equal to 30 cf/day.

I just wanted to point out that material did not change so the coefficient of permeability does not change. The hydraulic gradient and the cross sectional area of flow is what changes and results in significantly different flow rates.

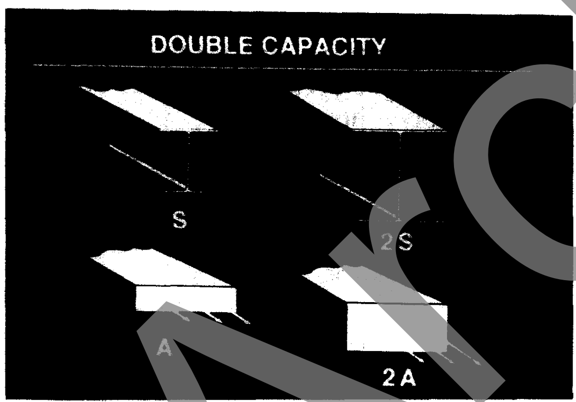
Darcy's Law can also be compared to the design of a steel beam. The coefficient of permeability of a base compares to the allowable steel stress of a beam.



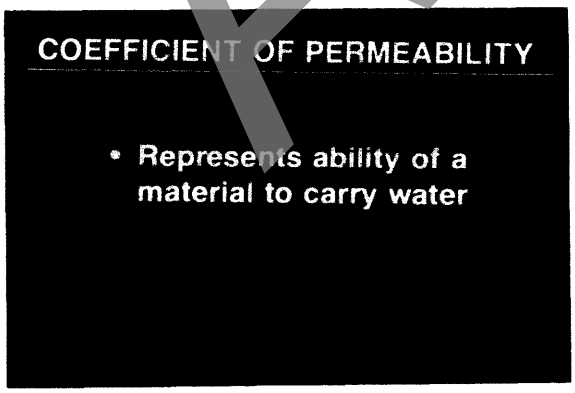
If the allowable steel stress of the beam is doubled then the load carrying capacity is doubled. Likewise, if the coefficient of permeability of a base is doubled, then the flow capacity of the base is doubled.



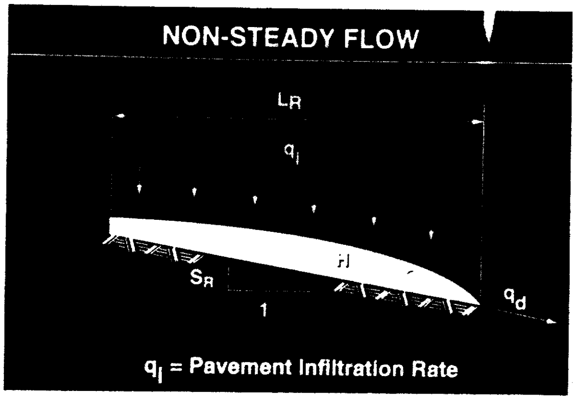
The cross sectional area of base can be compared to the section modulus of a structural steel beam.



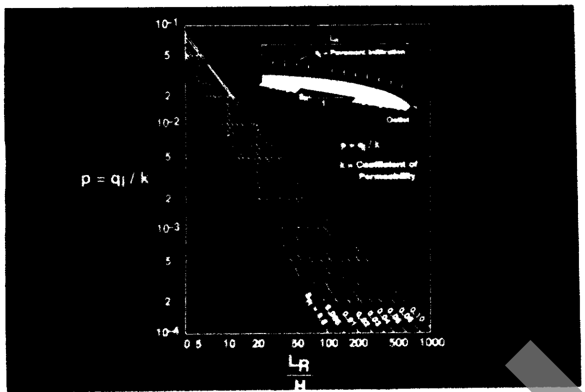
If the section modulus is doubled, then the load carrying capacity of the beam is doubled. Likewise, if the cross sectional area of the permeable base is doubled, then the flow capacity of the base is doubled.



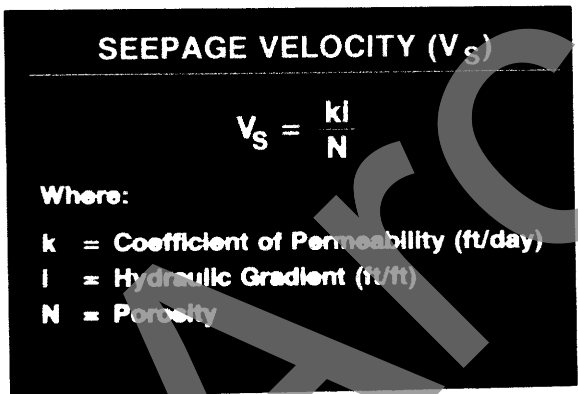
The coefficient of permeability of a material only represents the ability of that material to carry water.



Darcy's law assumes steady flow through the medium which is not always the case in the field. The depth of flow will increase until the drawdown effect of discharging the water into the edgedrain system is reached. The slope of the hydraulic gradient will change as the flow moves towards the edgedrain.



To model non-steady flow, this design chart was developed. The use of this design chart permits the determination of the maximum depth of flow in a drainage layer when the values of the infiltration rate (q_i), the coefficient of permeability (k) of the drainage layer, the length of the flow path (L_R), and the resultant slope of the flow path (S_R) are known. The coefficient of permeability required for a given base thickness can be determined.



Seepage velocity is the average velocity through the pore spaces of the aggregate or soil. Its units are in feet per day; however, it is not equal to the coefficient of permeability. Seepage velocity is the actual velocity of the water in the aggregate or soil and would be used to study particle transport in the base. Seepage velocity is determined by the following formula.

$$V_s = \frac{k\,i}{N}$$

V_s = Average velocity through the pore spaces, ft/day
k = Coefficient of permeability, ft/day
i = Hydraulic gradient, ft/ft
N = Porosity of the aggregate or soil.

DISCHARGE VELOCITY (V)

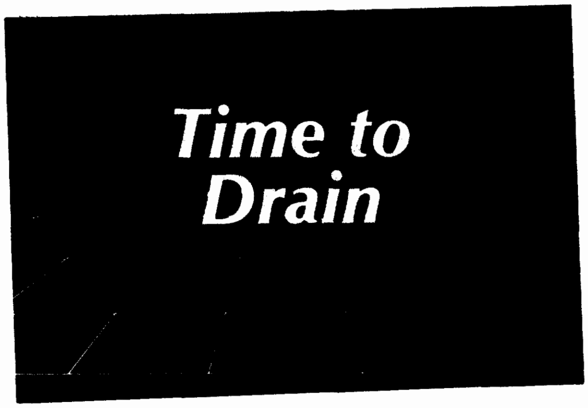
$$V = ki$$

Where:

k = Coefficient of Permeability (ft/day)

i = Hydraulic Gradient (ft/ft)

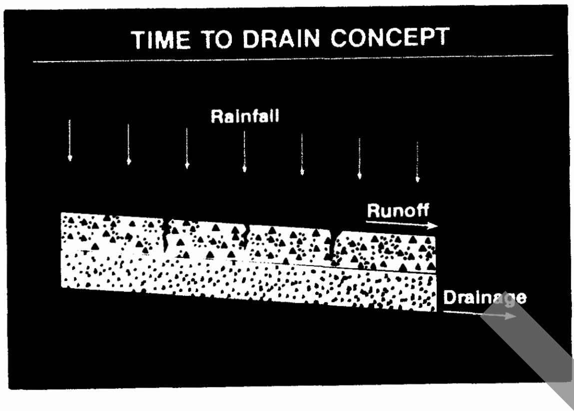
Discharge velocity is the nominal or average velocity through the aggregate or soil. It is the theoretical velocity of the water through the aggregate or soil. It is used to determine the time of flow between two points. $V = k\ i$



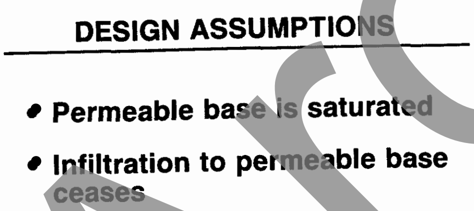
TIME TO DRAIN

Using the design chart or Darcy's law to determine the thickness of the permeable base required may result in a base course that is not very economical or practical to build.

If you remember in an earlier session we stated that there were a lot of assumptions that were made to determine the pavement infiltration rate. Knowing the limitations of the previous procedures, a lot of engineers use the TIME TO DRAIN procedure. It is the procedure that is recommended in this workshop.

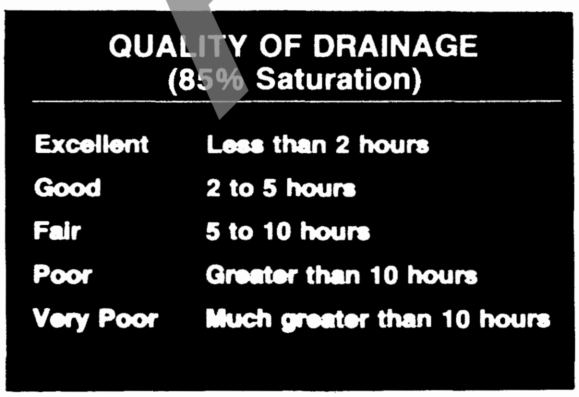


Time to drain assumes that when a rainfall event occurs, the rainwater will infiltrate the pavement until the permeable base is saturated. At that point, the excess water will runoff the pavement surface. After the storm event, the pavement will drain as designed.



The design assumptions for Time to Drain are:

- The permeable base becomes saturated during the storm.
- When the base is saturated, infiltration to the permeable base ceases.



The FHWA Rehabilitation Manual provides guidance based on the 85 percent saturation. Some engineers argue that the 85 percent saturation level is a better threshold for pavement damage due to moisture.

Quality of Drainage	Time to Drain
Excellent	Less than 2 hours
Good	2 to 5 hours
Fair	5 to 10 hours
Poor	Greater than 10 hours
Very Poor	Much greater than 10 hours

RECOMMENDED QUALITY OF DRAINAGE
(50% Drained)

Excellent	2 hours
Good	1 day
Fair	7 days
Poor	1 month
Very Poor	Does Not Drain

The AASHTO GUIDE for Time to Drain defines the quality of drainage based on draining 50 percent of the drainable water. It does not consider the water retained by the effective porosity of the material.

Quality of Drainage	Time to Drain
Excellent	2 Hours
Good	1 day
Fair	7 days
Poor	1 month
Very Poor	Does not drain

RECOMMENDED
TIME TO DRAIN
Highest Class Roads

50 Percent Drainage in 1 Hour

A time to drain 50 percent of the drainable water (effective porosity) in 1 hour is recommended as a criterion for the highest class roads with the greatest amount of traffic.

RECOMMENDED
TIME TO DRAIN
Most Interstates & Roads

50 Percent Drainage in 2 Hours

For other roadways, a time to drain 50 percent of the drainable water (effective porosity) in 2 hours is recommended. These are only target values. The goal of drainage should be to remove all drainable water as quickly as possible.

TIME TO DRAIN (t)

$t = T \times m \times 24$

Where:

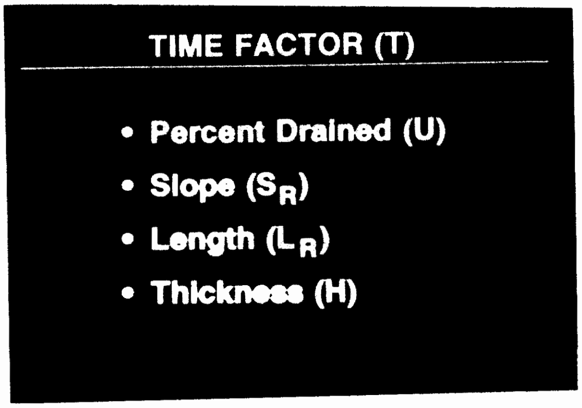
T = Time Factor

m = m Factor

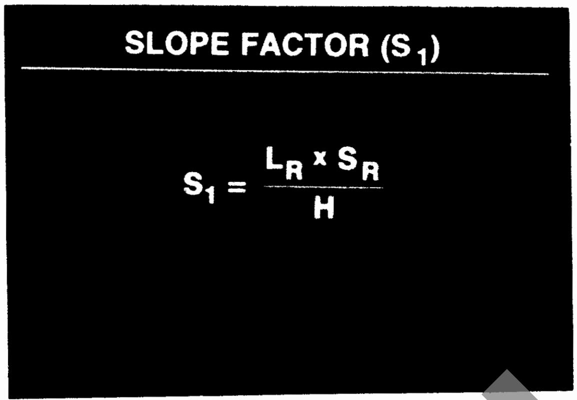
The time to drain is determined by the following formula.

$t = T \times m \times 24$, where

t = time to drain - hours
T = Time factor
m = "m" factor

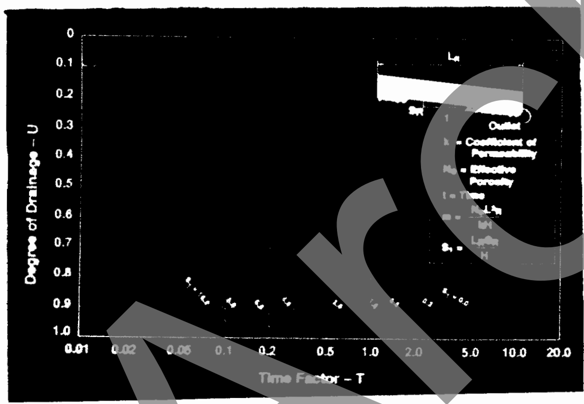


A design chart is used for determining the Time Factor (T). The Time Factor is based on the geometry and properties of the base course. The factors that make up the Time Factor are: the resultant slope (S_R), and resultant length (L_R), the thickness of the base (H), and the percent drained (U).

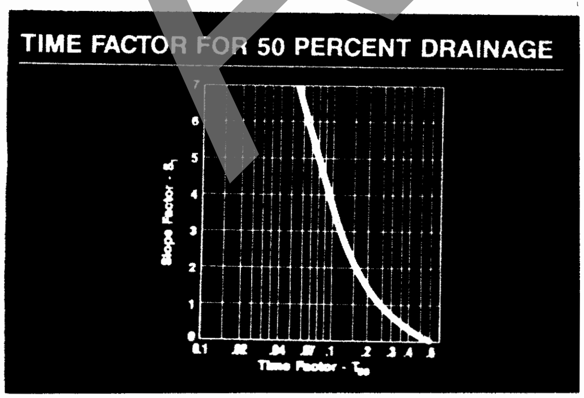


The slope factor s_1 is an input to the chart and is calculated by:

$$S_1 = \frac{L_R\, S_R}{H}$$



This is the design chart for determining the Time Factor. The Slope Factor are shown as a family of curves. If we select a percent drained, for example 50 percent drained.



We can develop a simplified Time Factor chart for 50 percent drained.

M FACTOR (m)

$$m = \frac{N_e (L_R)^2}{k\ H}$$

Where:

N_e = Effective Porosity

k = Coefficient of Permeability (ft/day)

H = Layer Thickness (ft)

L_R = Resultant Length (ft)

The "m" factor is determined by

$$m = \frac{N_e\ L_R^2}{k\ H}$$

N_e = Effective porosity
L_R = Resultant length, ft
k = Coefficient of permeability, ft/day
H = Thickness of the base, ft

TIME TO DRAIN (t)

$$t = T \times m \times 24$$

Where:

T = Time Factor

m = m Factor

Time to Drain Equation

t= T * m * 24

t = time to drain
T = Time Factor
m = m Factor

- **Evaluate time to drain and percent drained**

We want to evaluate time to drain over a range of drainage conditions rather than one drainage condition.

PERCENT DRAINED

- **Assign percent drained**
- **Calculate time to drain**
- **Evaluate time to drain**

First we assign a percentage of the water we want to drain from the permeable base.

Next we calculate the time to drain for that percent drained.

We would perform the time to drain over a range of percent drained, so that we could evaluate the different time to drain.

PERCENT SATURATION

- Assign percent drained
- Calculate time to drain
- Calculate percent saturation
- Evaluate data array

If we wanted to evaluate the percent saturation at given times, we would first assign a percent drained from the permeable base.

Next, we calculate the time to drain for that percent drained.

Then we calculate the percent saturation at that time.

We would perform the calculations over a range of percent drained, so that we could evaluate the different percent saturation.

100% SATURATION

$$V_W = V_V = N$$

For 100 percent saturation, the volume of water is equal to the volume of the voids which is numerically equal to the porosity.

PERCENT SATURATION (S)

$$S = \left(\frac{V_W}{N}\right) \times 100$$

V_W = Volume

N = Porosity $- V_V$

Percent saturation is equal to the volume of water divided by the porosity times 100 percent.

WATER DRAINED

$$\text{Water Drained} = N_e \times U$$

N_e = Effective Porosity

U = Percent of Drainage

Water drained is equal to the effective porosity time the percent of drainage.

WATER RETAINED (V_W)

$$V_W = V_V - (\text{Water Drained})$$

Where:

V_V = Volume of Voids

Water Retained is equal to the volume of the voids minus the water drained.

Substituting:

$$V_V = N$$

Assuming a unit volume, we can substitute volume of voids for porosity

WATER RETAINED (V_W)

$$V_W = N - (\text{Water Drained})$$

Where:

N = Porosity

The water retained is equal to the porosity minus the water drained.

PERCENT SATURATION (S)

$$S = \left(\frac{V_W}{N}\right) \times 100$$

V_W = Volume

N = Porosity $-V_V$

Percent saturation is equal to the volume of water divided by the porosity times 100 percent.

- **Evaluate time to drain and percent saturation**

We also want to evaluate time to drain and percent saturation.

Computation Procedures

We will take a look at the computation procedures for Time to Drain.

Identify parameters:

- S_R
- L_R
- H
- K
- N_e

We need to identify the following parameters for the permeable base

S_R - resultant slope
L_R - resultant length
H - base thickness
k - coefficient of permeability
N_e - effective porosity

K and N_e represent the rate and amount of water that will drain from the base.

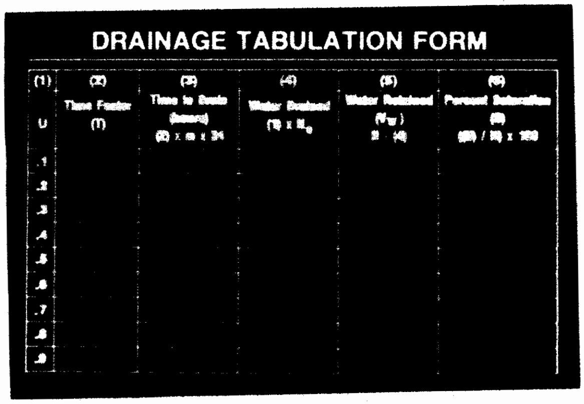
Calculate:

- $S_1 = \dfrac{L_R \ S_R}{H}$
- $m = \dfrac{N_e \ (L_R)^2}{k\,H}$

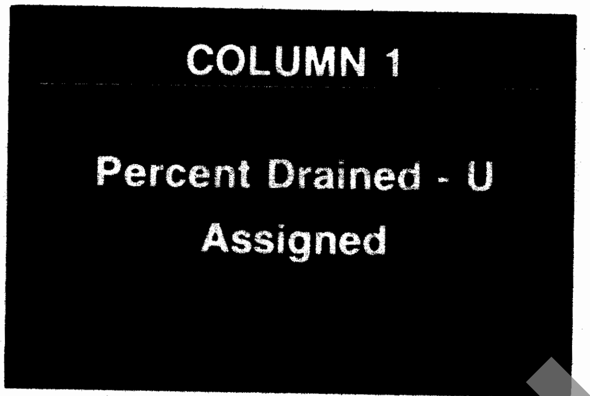
We need to calculate the slope factor and the m factor. They can be calculated by the following equations.

$$S_1 = \frac{L_R S_R}{H}$$

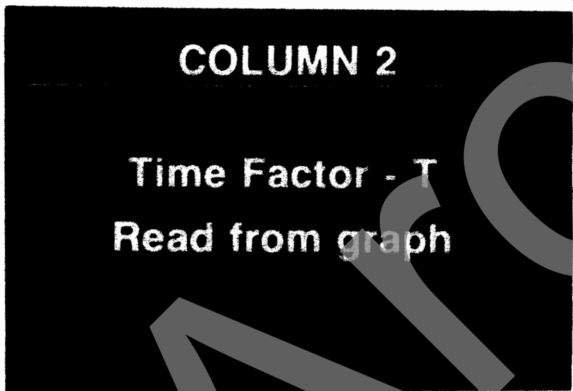
$$m = \frac{N_e L_R^2}{k\,H}$$



This table is a design form that was designed to evaluate permeable base drainage over a wide range of drainage conditions. This form allows an engineer to evaluate the sensitivity to the different degrees of drainage for a given design.



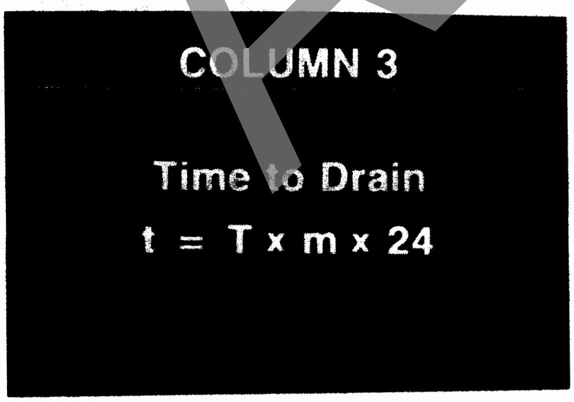
The first column represents the percent drained (U). The percent drained is varied from 10 percent to 90 percent.



The second column is the Time Factor (T). The time factor is determined by calculating the Slope factor (S_1)

$$S_1 = \frac{L_R\, S_R}{H}$$

Then enter figure 27 with the Percent Drained (U) and the Slope Factor (S_1) to determine the Time Factor (T).



Column 3 in the Time To Drain (t) in hrs. Remember that t = T x m x 24

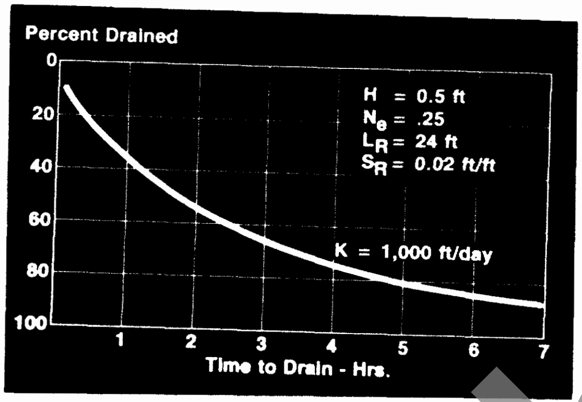
T has been determined and recorded in Column 2 and

$$m = \frac{N_e\, L_R^2}{k\, H}$$

PERCENT DRAINED GRAPH

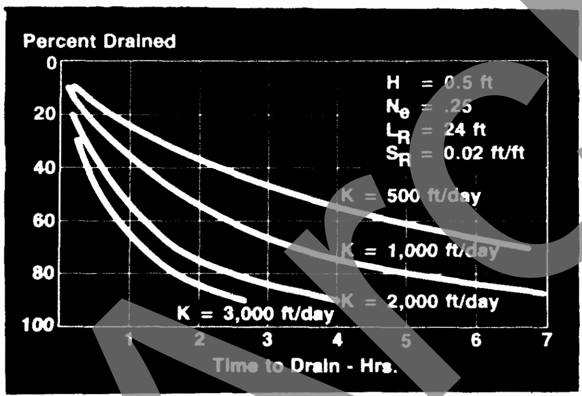
Plot Column 3 vs. Column 1

After completing column 3, we would plot column 1 versus column 3 so that the relationship between percent drained and time to drain could be evaluated.



For a permeable base that is 6 inches in thickness, with a coefficient of permeability of 1000 feet/day, an effective porosity of 0.25, resultant length of 24 feet, and resultant slope of 0.02 ft/ft, the relationship between percent drained and Time to Drain is shown in this sketch.

As the percent drained is increased, then the time to drain increases. It takes a little less than 2 hours to drain 50 percent and 7 hours to drain 85 percent.



If we wanted to change the time to drain for various percent drained, we could change the coefficient of permeability of the permeable base.

If this was an Interstate highway, we would want 50 percent of the effective porosity drained in one hour. You can see that the bases with coefficient of permeability of 2000 and 3000 feet/day would meet our design criteria.

For other routes, we would want 50 percent of the effective porosity drained in 2 hours. A permeable base with a coefficient of permeability of 1000 feet/day or higher would meet the design criteria for the given conditions.

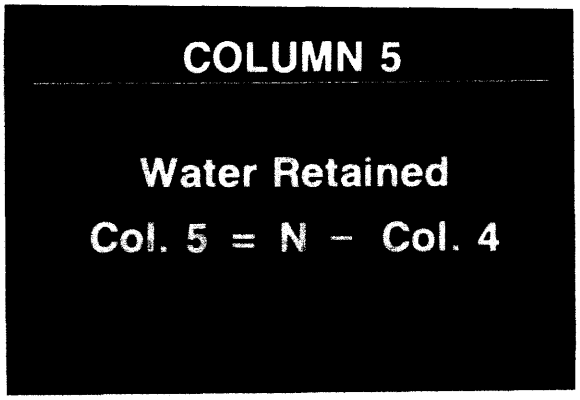
COLUMN 4

Water Drained

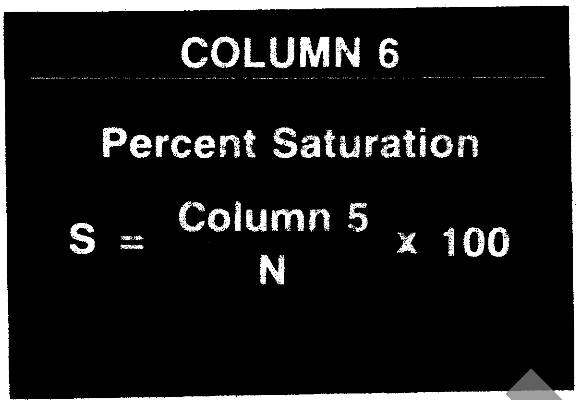
Col. 4 = N_e x U

If the design standard is percent saturation then we would continue the calculation and complete column 4.

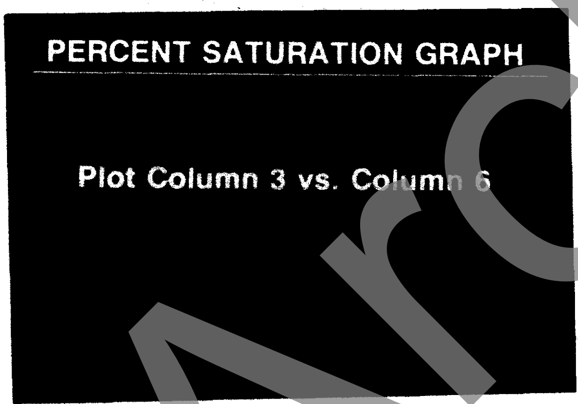
The drained water = Percent Drained (U) multiplied by the Effective Porosity (N_e). Percent Drained (U) has been recorded in column 1.



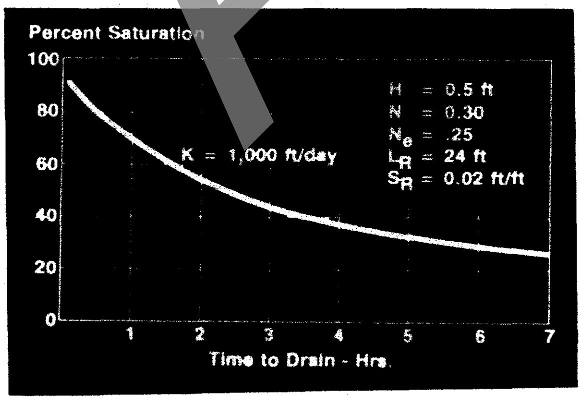
Column 5 is the Water retained. The Water Retained is the volume of water (V_w) which is equal to the volume of voids (V_v) minus the drained water. For V_v, the water retained is then equal to porosity minus column 4.



Column 6 is the percent saturation (S). Saturation is the ratio of volume of water (V_w) to the volume of voids (V_v). The volume of water is the water retained (Column 5) and the volume of voids is porosity (N). Therefore, Column 6 is equal to column 5 divided by N times 100 percent.



After filling in the table, a percent saturation chart should be developed. We can do this by plotting column 3 versus column 6.



Using the same permeable base, that is 6 inches in thickness, with a coefficient of permeability of 1000 feet/day, porosity of 0.30, resultant length of 24 feet, and resultant slope of 0.02 ft/ft.

You can see that the permeable base percent saturation decrease as the time to drain increases.

Percent Drained	Time to Drain (Hours)	Percent Saturation
0.1	0.099	91.67
0.2	0.357	83.33
0.3	0.732	75.00
0.4	1.197	66.67
0.5	1.734	58.33
0.6	2.404	50.00
0.7	3.373	41.67
0.8	4.928	33.33
0.9	8.025	25.00

This a computer printout of the Percent of the drainable water versus Time to Drain versus Percent Saturation.

Assuming the roadway was other than an Interstate. the permeable base in its design configurations would meet our recommended design criteria. For 50 percent drained, the Time to Drain for the permeable base is 1.734 hours and the percent saturation is 58.33.

Notice that the percent saturation is 58.33 for the 50 percent drained. The reason for this is that the percent drained is of the drainable water or effective porosity. The percent saturation considers the total volume of water in the volume of voids which is equal to porosity.

Notice that 85 percent saturation will occur in 0.2 hours with only 35.7 percent water draining.

Highway Subdrainage Design by Microcomputer

DAMP

The Federal Highway Administration has developed a microcomputer program DAMP which will perform the time to drain calculations. However, there has been some trouble using DAMP with Time to Drain calculations.

Drainage Analysis Modeling Programs

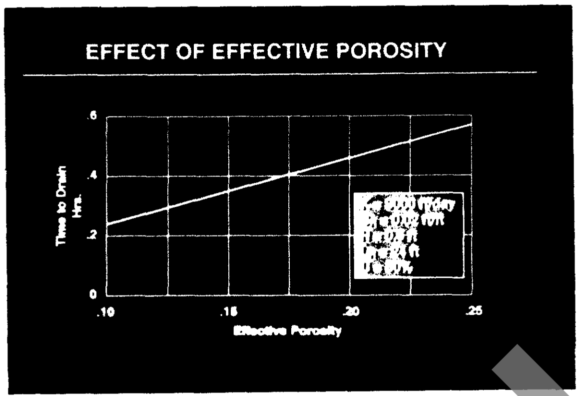
DAMP stands for Drainage Analysis Modeling Programs.

Whenever you use a computer program you should not accept the output blindly. One should test the computer program by performing a sensitivity analysis of all the variable into the equation.

- McTrans 904-392-0378
  University of Florida
- PC Trans 913-864-5655
  University of Kansas

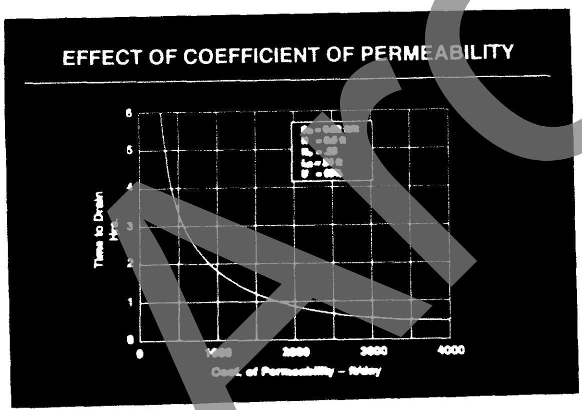
Telephone numbers where the program can be obtained.

It is important that pavement design engineers understand the effects of various parameters in time-to-drain calculations. The best way to investigate the problem is to perform sensitivity analysis on the design procedures. In a sensitivity analysis, each parameter is investigated over a range of values while the remaining variables are held constant.



Effective porosity is a factor which represents the drainage capability of the base material. It is used in the "m" factor equation. The relationship between effective porosity to time to drain is linear. When the effective porosity is doubled, the time to drain is doubled. Upon first glance of this analysis, one might be tempted to reduce the effective porosity so that the time to drain is reduced. THIS WOULD BE A GRAVE MISTAKE.

Remember that as the effective porosity increases, the amount of water drained increases. With all other factors held constant it makes sense that it is going to take longer to drain more water. Since we want to drain more water then we should always use materials with higher effective porosities.

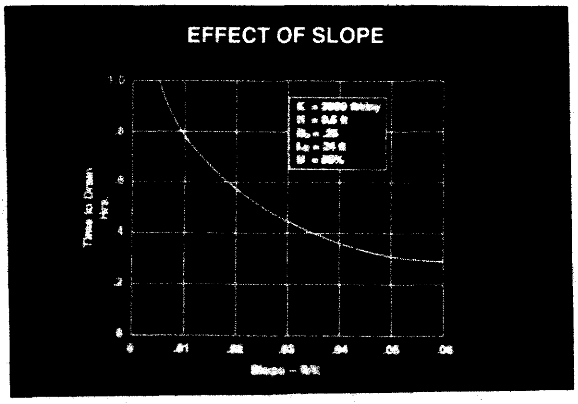


Coefficient of permeability is the other factor which represents the drainage capability of the base material. It is used as a denominator in the "m" factor equation, therefore the time to drain is inversely proportional to the coefficient of permeability.

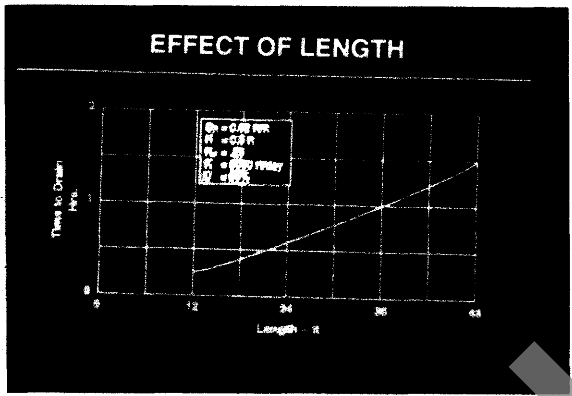
As the coefficient of permeability increases, the time to drain decreases or the faster the base will drain.

You can see that as the Time to Drain starts to reduce more slowly as the coefficient of permeability exceeds 2000 feet per day for the given assumptions. It may be more cost effective to try to change another variable to reduce time to drain.

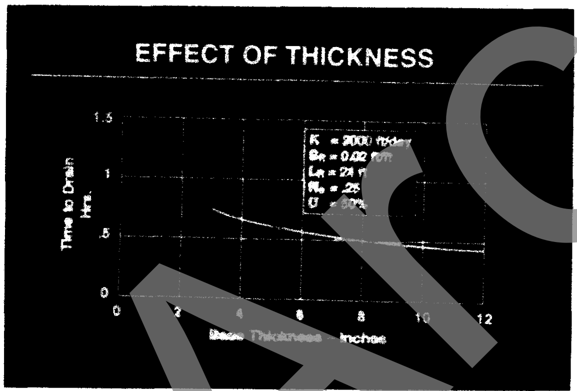
You can also see that the time to drain increases sharply once the coefficient of permeability drops below 1000 feet per day. You can see why we recommend a minimum coefficient of permeability of 1000 feet per day.



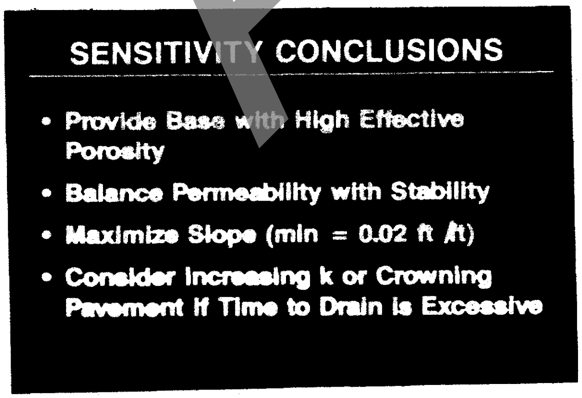
The resultant slope is a variable in the Time factor (T). The sensitivity analysis shows that as the resultant slope increases, the time to drain decreases. The steeper the slope the faster the water will drain.



The resultant length is a variable in both the "m" factor and the Time Factor (T). As the resultant length increases, the time to drain increases. This makes sense because the resultant length is basically the flow path through the base. If the path length is increased the time to drain should also increase.

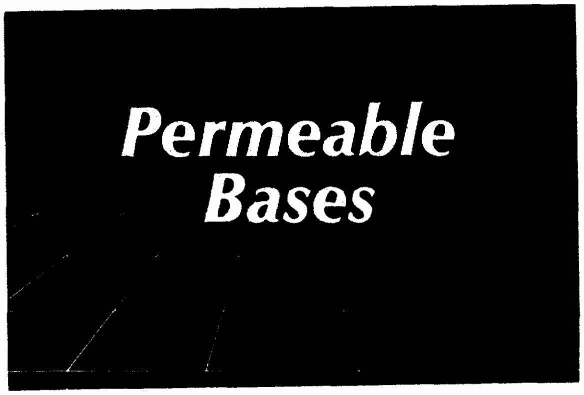


The thickness is a variable in both the "m" factor and the Time factor. The sensitivity analysis shows that the base thickness has little effect of the time to drain.



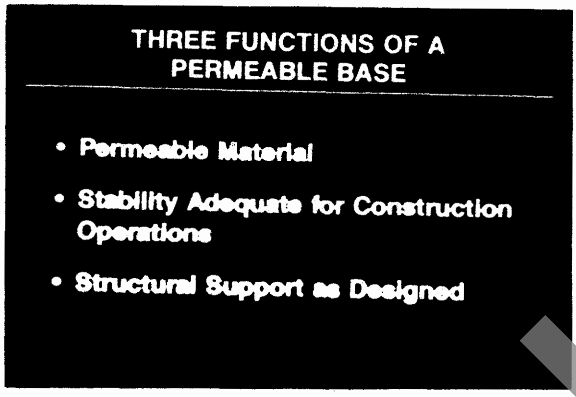
Based on the sensitivity analysis, the following guidance is given:

- Provide a base course material with high effective porosity.
- Provide a base course material with as high a coefficient of permeability that the construction permits.
- Provide as much slope as possible. A minimum slope of 0.02 ft/ft is recommended.
- If the time to drain is too long, the consider increasing the coefficient of permeability or providing crowned pavement sections to reduce the length of the flow path.



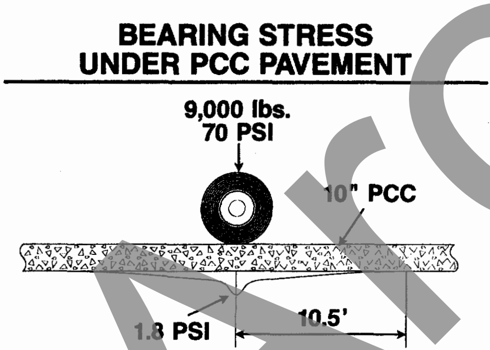
Permeable Bases

In the past, the primary function of the base course was to provide uniform support. However, as wheel loads increased, pumping and erosion of the underlying materials resulted. Engineers developed stabilized bases which were thought to be strong and non-erodible. Time has shown that these materials were not only impermeable but also erodible as well. To solve this problem, a number of States are using an open graded base material to rapidly drain infiltrated water from the pavement structure. This type of material is called a permeable base.

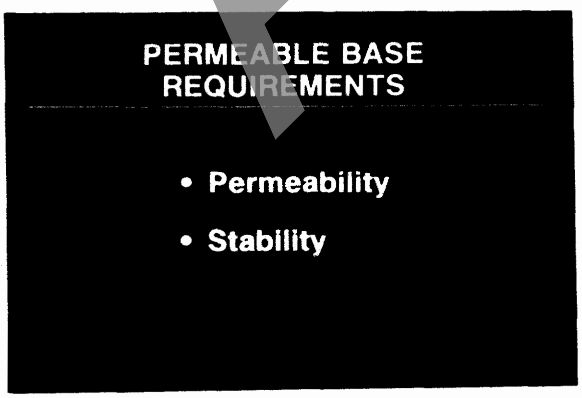


A permeable base must provide three very important functions:

- The base material must be permeable enough so that the base course drains within the design time period.
- The base course must have enough stability to support the pavement construction operation.
- The base course must have enough stability to provide the necessary support for the pavement structural design.

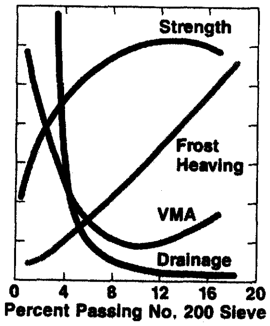


Mechanistic equations can be used to model stresses and strains in a pavement structure. An analysis was performed for this situation. A 9000 lb load with a tire pressure of 70 psi passing over 10" of concrete pavement. The maximum stress on the permeable base would be 1.8 psi directly under the load. Much higher stresses are placed on the permeable base during construction (100 psi truck tires not uncommon). If the permeable base can survive construction traffic, it should provide adequate support for the pavement.



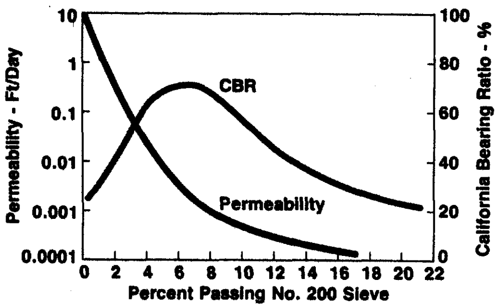
The open graded base course must provide permeability to remove the water rapidly. It must also be able to provide support or stability to resist construction loadings.

The design of a permeable base is often a balance between stability and permeability.



This a plot of percent passing the No. 200 sieve versus various different material properties to illustrate the trade-off between strength and drainage.

As the percent passing the No. 200 sieve increases, the stability increases to a peak then breaks over. The permeability will decrease as the amount of minus 200 material increases.



Here is another graph showing a material's CBR value and its coefficient of permeability versus the amount passing the No. 200 sieve.

The CBR increases to a peak of around 7 percent as the minus 200 increases. The coefficient of permeability decreases as the minus 200 material increases.

STABILITY

Stability is primarily determined by:

- **Quality of aggregates**
- **Particle size and distribution**
- **Stabilizer material**

Stability of a base material is primarily determined by:

Quality of Aggregate - Aggregate shape and texture

Particle Size and Distribution

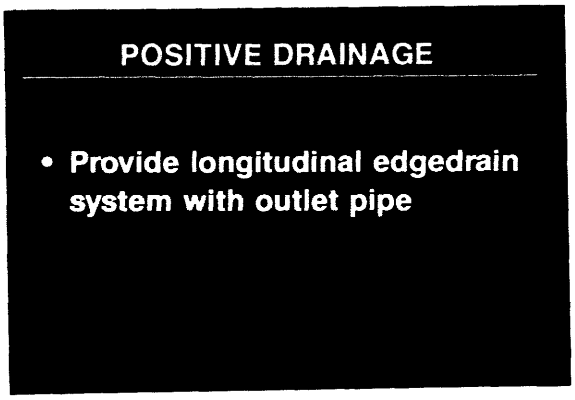
Stabilizer Material

PERMEABILITY

Permeability is primarily determined by:

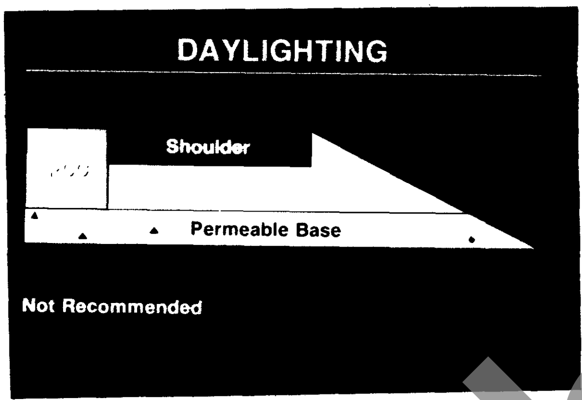
- **Particle size and distribution**

The coefficient of permeability of a material is primarily determined by its particle size and distribution.

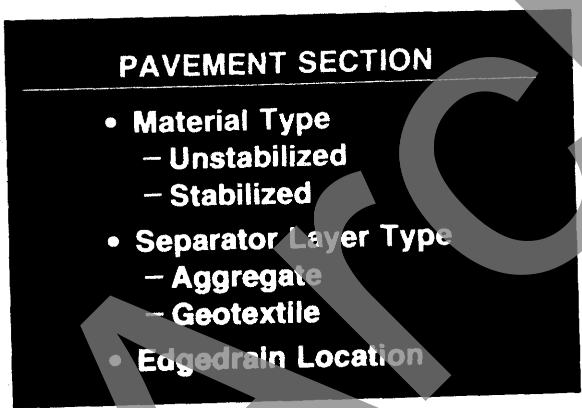


When using a permeable base course, positive drainage, in the form of longitudinal edgedrains with outlet pipes, must be provided.

If positive drainage is not provided, the permeable base will act as a sponge and will increase the rate of pavement deterioration.



Daylighting the permeable base to the ditch is not considered positive drainage and is not recommended. Daylighted layers are often clogged by roadway debris and vegetation.

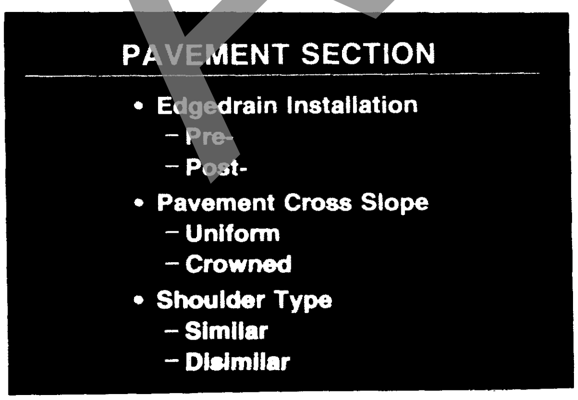


Pavement drainage is just one element of pavement design. It does not replace other requirements such as pavement thickness, positive load transfer, and a strong, uniform subgrade. Factors that make the pavement section design difficult include:

Use of Stabilized or Unstabilized Base Materials

Which type of separator layer to use in between the subgrade and the permeable base.

The location of the longitudinal edgedrain.

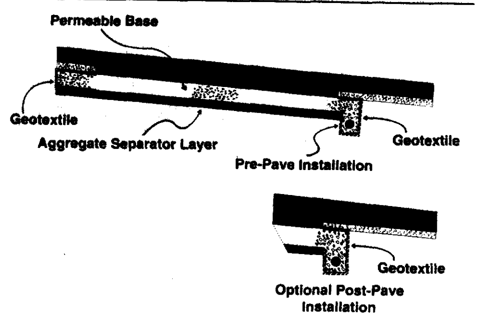


When should the edgedrain be installed, prior to paving or after paving?

Should a multilane facility have a uniform cross slope or should a crown section be provided?

What type of shoulder type should be provided, asphalt or tied concrete?

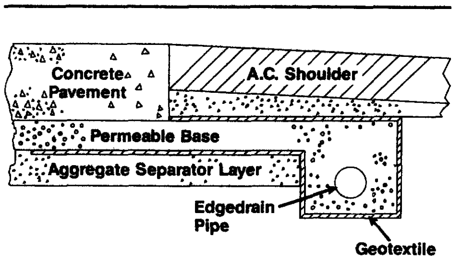
EDGEDRAIN LOCATION - A.C SHOULDERS



Let's look at edgedrain installation locations.

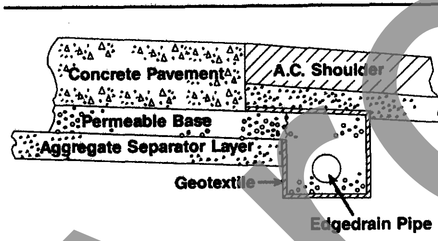
For a concrete pavement with asphalt shoulders, it is anticipated that this joint will open up over time due to dissimilar materials. In this case we want to locate the edgedrain as close as possible to the joint to reduce the flow path for the infiltrated water. With the uniform cross slope, the infiltrated water will drain to the outside ditch.

PRE-PAVE INSTALLATION

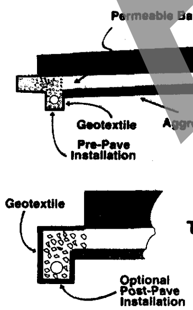


For the pre-pave installation, the edgedrain is located far enough away from the edge of the concrete pavement so that the paver tracks will run on top of the permeable base and not directly over top of the edgedrain trench. The trench is wrapped with a geotextile to prevent the migration of fines into the edgedrains. The edgedrain should not be located underneath the concrete slab, as non uniform slab support may result.

POST PAVE INSTALLATION



For the post-pave installation, the edgedrain trench is located far enough away from the pavement slab, so that the slab will not lose support by the permeable base eroding or sloughing during the trenching operation. The trench should be backfilled with material as permeable as the permeable base, so there will not be a loss of permeability. The edgedrain trench is wrapped with a geotextile to prevent contamination of subgrade fines.

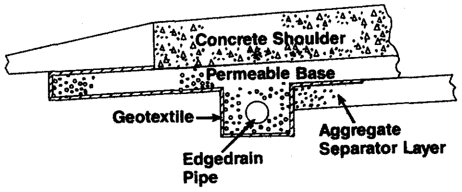


EDGEDRAIN LOCATION
TIED CONCRETE SHOULDERS

Crowned concrete pavement with tied concrete shoulders. Since the pavement is crowned, edgedrains must be provided on both sides of the roadway. The crowned section improves drainage as it reduces the flow path and the Time to Drain.

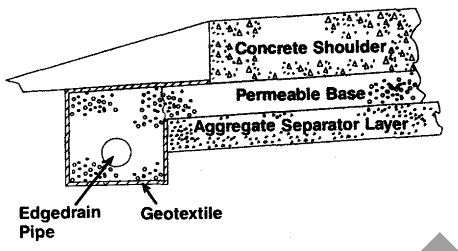
The tied concrete shoulders will provide considerable support to the edge of the concrete pavement slab. The life of the joint sealant should be improved as the tied shoulder will move less.

PRE-PAVE INSTALLATION



For the pre-pave installation, the edgedrain trench may be located underneath the shoulder to avoid the paver tracks during construction. The trench should not be located underneath the pavement slab. A geotextile is provided to prevent fines from entering the edgedrain trench.

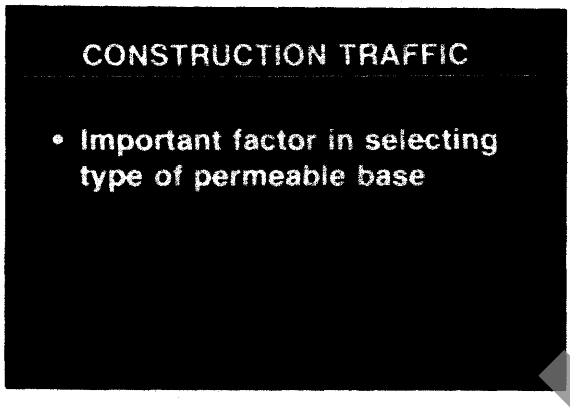
POST PAVE INSTALLATION



For the post pave installation, the trench should be located far enough outside the shoulder that there is no loss of support underneath the concrete shoulder during trenching operations.

Again the trench is wrapped with a geotextile.

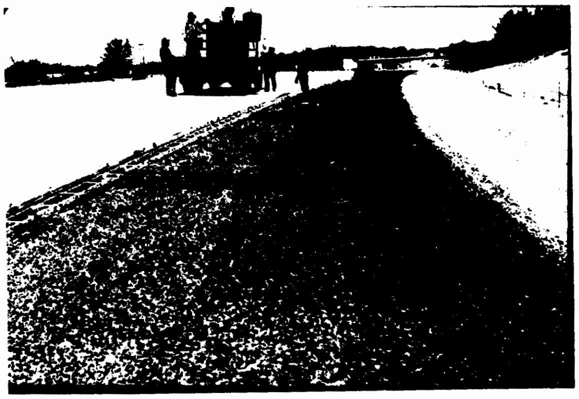
Construction Traffic



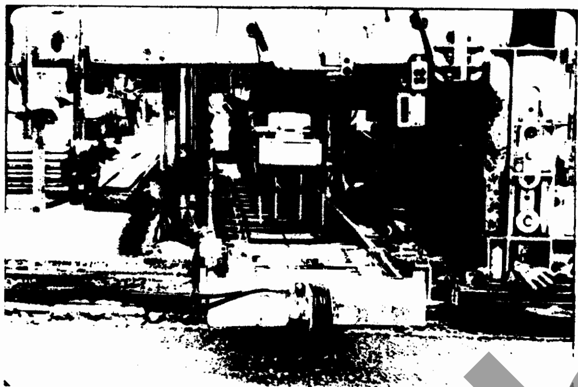
Construction traffic on the completed base course is the single most important parameter in the selection of the type of the permeable base to be used. If there will be a lot of construction traffic on the base course, then an asphalt or a cement stabilized base is generally used. If there will not be any traffic on the base course, then an untreated open graded material could be used.

As the concrete is placed on the grade, a spreading machine will distribute the concrete evenly across the width of the pavement. A paver will follow the spreader machine. Notice that the tracks are running on top of the permeable base. We want to make sure the edgedrain is located outside of the paver track to minimize damage to the edgedrain pipe.

If width is restricted, or maintenance of traffic is tight, delivery trucks may have to operate on the permeable base. We want to minimize the amount of construction traffic on the permeable base to prevent contamination from fines tracking on the wheels.



When dowel baskets are used, special attention should be given to anchoring techniques on drainable bases.



Some pavers are equipped with dowel bar inserters.

CONSTRUCTION TRAFFIC

None	Unstabilized
Moderate	Unstabilized $C_u > 4$
Heavy	Asphalt or Cement Stabilized

The following guidance is given in the type selection of permeable bases for construction traffic.

If the construction traffic is moderate to minimal, you can use an unstabilized base, if the coefficient of uniformity of the base is greater than 4.

If a lot of construction equipment will be operating on the permeable base, then an asphalt or cement stabilized base should be considered.

CONSTRUCTION TRAFFIC

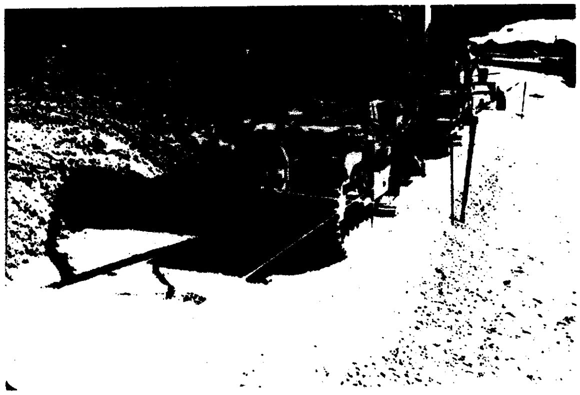
- Keep Volume Down
- Keep Speed Down
- Gentle Turning
- Gentle Starting and Stopping

Really we should strive to keep the construction traffic volume down, to minimize contamination and damage, no matter which type of permeable base is used.

Speeds should be keep to a minimum, with gentle turning movements.

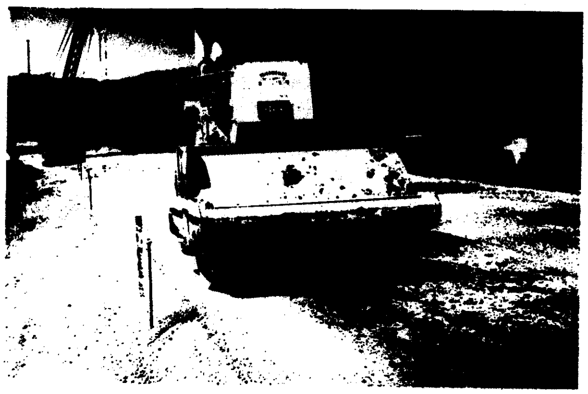
Vehicles should start and stop slowly and smoothly.

We don't want drag races and skid tests on permeable base course. Remember, permeable bases require care during construction to minimize damage.



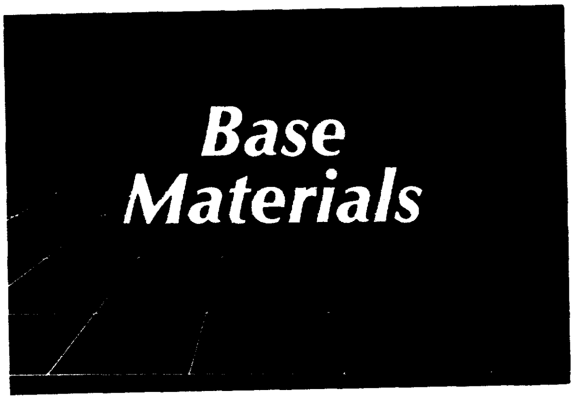
Things to look for in the permeable base and the construction area prior to paving. The stringline plays an important role in obtaining ride quality. Always check the stringline and make sure that it is not bumped or touched during construction.

The path the paver track rides over must provide uniform support for good ride.

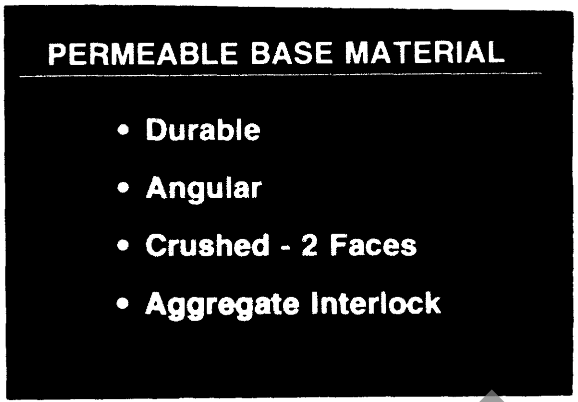


Contractor is making pass with the roller over the track line on the permeable base.

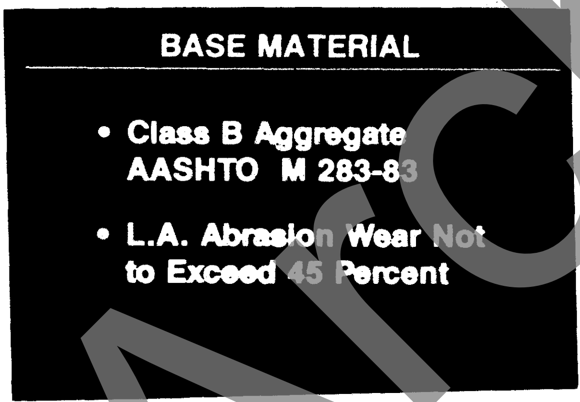
Extra permeable base may have to be placed to keep the paver track off of the permeable base edge. There is less support at the unconfined edge of the permeable base. It is also a good idea to keep the paver track line from being directly over the edgedrain in the pre-pave installation. Remember to always check the stringline.



Base Materials

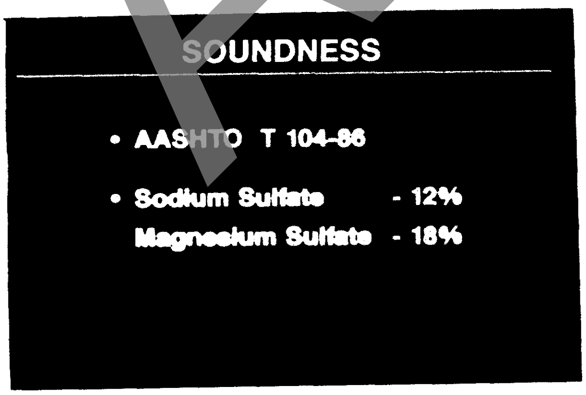


Both unstabilized and stabilized permeable base materials should consist of durable, crushed, angular aggregate with essentially no fines. The crushed aggregate should have at least two mechanically fractured faces, as determined by the material retained on the number 4 sieve. These properties are essential for a permeable base, because stability is obtained through aggregate interlock.



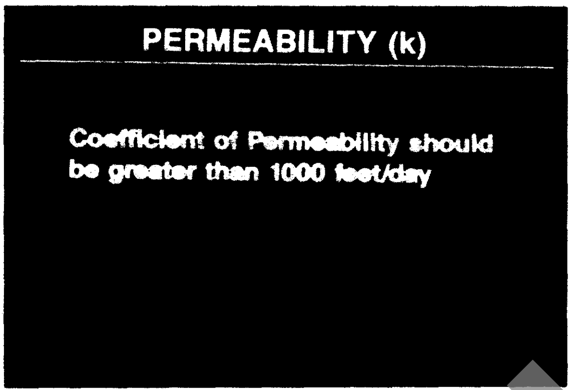
The FHWA recommends that only crushed stone be used in permeable bases. The aggregate should, as a minimum, meet the requirements for a Class B aggregate in accordance with AASHTO M 283-83, Coarse Aggregate of Highway and Airport Construction.

The L.A. Abrasion Wear should not exceed 45 percent as determined by AASHTO T 96-87, Resistance to Abrasion of Small Size Course Aggregate by Use of the Los Angeles Machine.

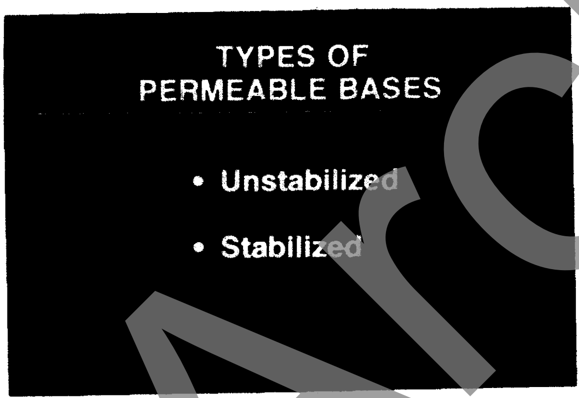


If the permeable base will be subjected to freeze-thaw cycles, the durability of the aggregates should be tested by a soundness test. The soundness percent loss should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests. These tests are conducted in accordance with AASHTO T 104, Soundness for Aggregate by the Use of Sodium Sulfate or Magnesium Sulfate.

The permeable base should of course be permeable enough to dissipate the water. This is a photo of a stabilized permeable base.



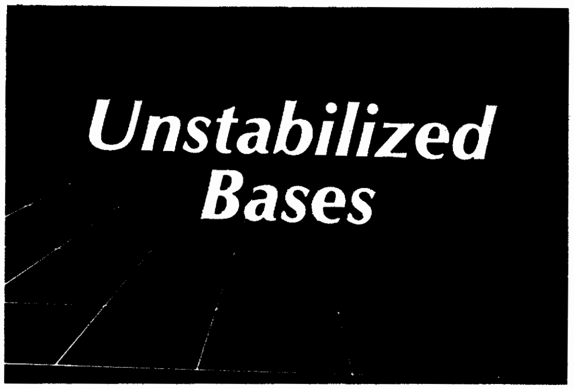
Since the in-place coefficient of permeability can vary significantly from the design coefficient of permeability, a minimum design coefficient of permeability of 1,000 feet per day is recommended.



The two types of permeable base materials are:

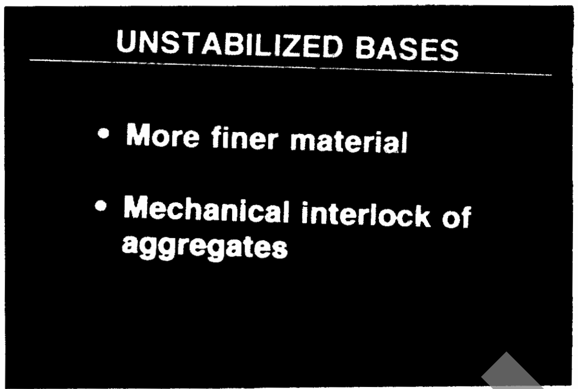
1. Unstabilized.

2. Stabilized.

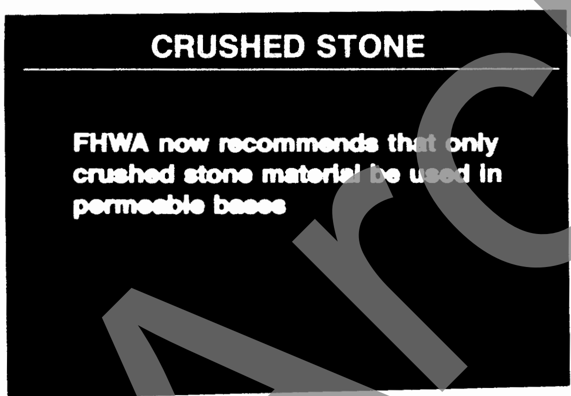


Unstabilized Bases

States that have developed an unstabilized permeable base gradation which represents a trade-off of constructability/stability and permeability.



Unstabilized materials contain more finer size aggregate to provide stability through increased aggregate interlock; however, this results in lower coefficient of permeabilities. Unstabilized permeable bases generally have a coefficient of permeability in the range of 1,000 to 3,000 feet per day.



To provide good stability for paving equipment, the FHWA recommends that the unstabilized permeable bases consist of 100 percent crushed stone.

Photo of a Quarry

COEFFICIENT OF UNIFORMITY (C_U)

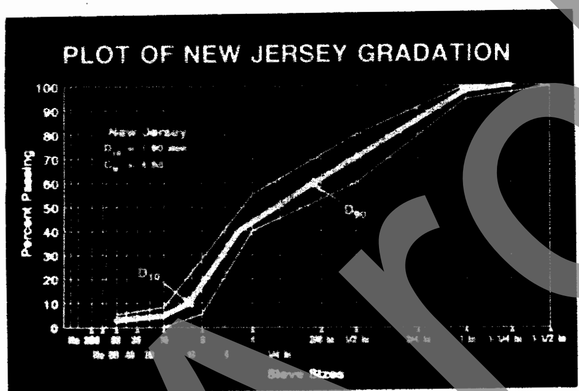
Greater than 4

The coefficient of uniformity of unstabilized permeable base courses should be greater than 4 to provide the required stability during construction.

UNTREATED PERMEABLE BASE (New Jersey Gradation)

Sieve Size	Percent Passing
1-1/2"	100
1"	95 - 100
1/2"	60 - 80
No. 4	40 - 55
No. 8	5 - 25
No. 16	0 - 8
No. 50	0 - 5

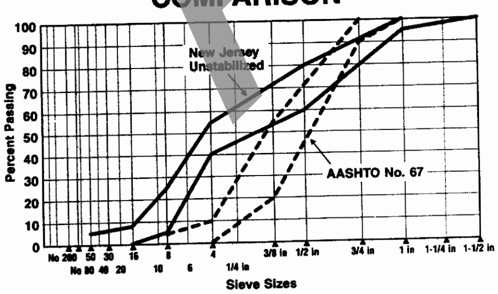
New Jersey Department of Transportation unstabilized permeable base gradation.



The New Jersey DOT gradation plotted on the gradation chart. The effective size of the gradation is 1.90 mm. Determining D_{60} and dividing it by the effective size will obtain a coefficient of uniformity of 4.68.

We measured the coefficient of permeability of this gradation to be approximately 1500 feet per day.

COMPARISON



The New Jersey unstabilized gradation plotted on the gradation chart. The midband of the AASHTO No. 67 gradation is also plotted on the gradation chart.

To increase stability of the New Jersey unstabilized base, the gradation contains more fine aggregate. This is shown on the chart. The New Jersey unstabilized base gradation is plotted to the left of the AASTHO No. 67.

UNSTABILIZED BASE COMPACTION

- 1 to 3 passes of 5-10 ton steel wheel roller

or

- Vibratory roller with care

Compaction of an unstabilized permeable base is obtained with 1 to 3 passes of a 5 to 10 ton steel wheeled roller.

If a roller is used in the vibratory mode, it should be done so with extreme caution.

Over rolling can cause degradation of the material resulting in lower permeabilities.

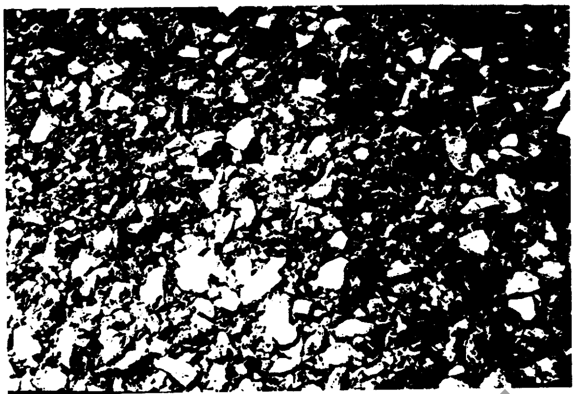
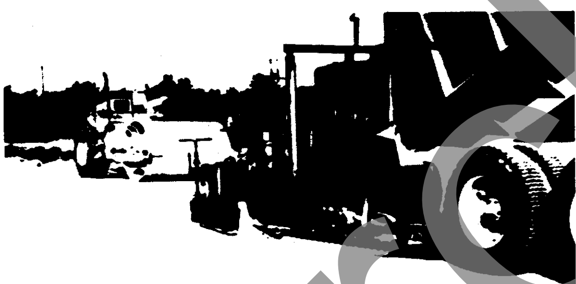
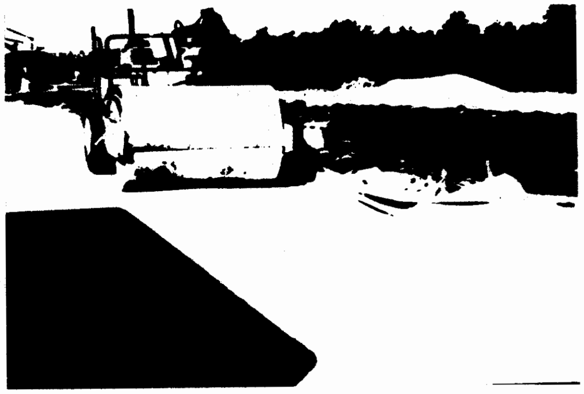


Photo of New Jersey DOT unstabilized permeable base. Notice the material is not as tight as a typical compacted dense graded base would appear.



The unstabilized permeable base is being placed by an asphalt paver. Notice that the paver is not operating off of grade controls. A minimum of thickness of 4 inches should be obtained.

Photo of the unstabilized base being placed.



Compaction of the unstabilized permeable base is not typical of dense graded base compaction. We are not looking for a target density or roller pattern. We want 1 to 3 passes of a 5 to 10 ton roller just to seat the aggregate to develop aggregate interlock for stability. Over rolling could result in degradation of the permeable base resulting in lower permeabilities.

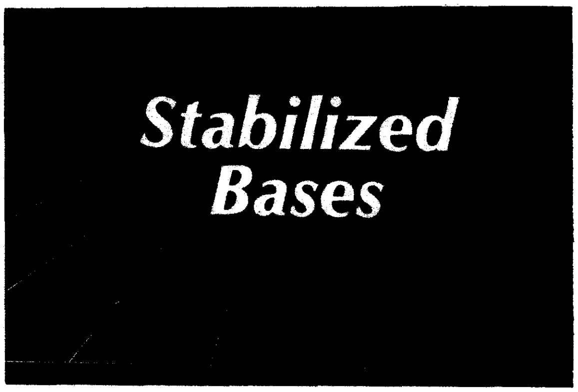
Final compaction of the permeable base. Do not worry about track marks as long as the base is stable to support construction traffic without rutting.

The texture of the permeable base course should still look open after compaction.

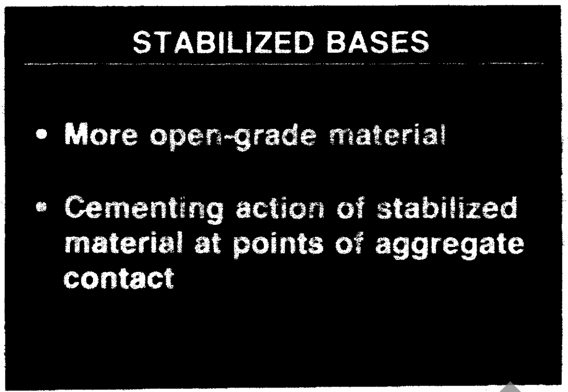
Placing unstabilized permeable base with a Blaw Knox variable width paver. The paver is fully extended and fixed extensions have been addedto the paver. Notice that both sides of the paver are operated off of stringlines. Very good texture behind a paving machine.

The edgedrain trench is wrapped between the time of installation and the placement of the permeable base to prevent contamination. Remember to unwrap the trench prior to placing the permeable base. Do not place restrictions in the water flow path between the permeable base and the edgedrain pipe. It is not a good idea to place the grade control stake in the edgedrain trench. This may damage the edgedrain.

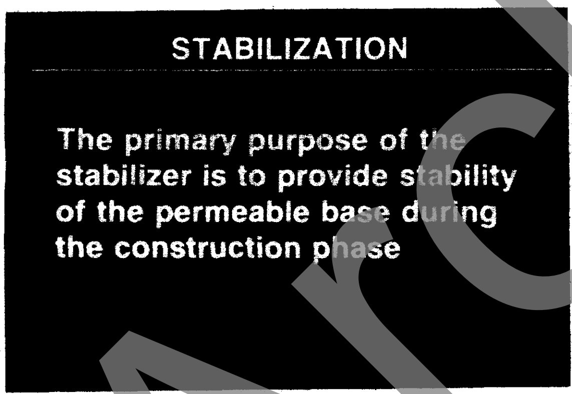
The concrete paver is straddling the permeable base and the tracks are operating on the dense graded aggregate base. The paver is going to place the concrete over the dowel bar assembly.



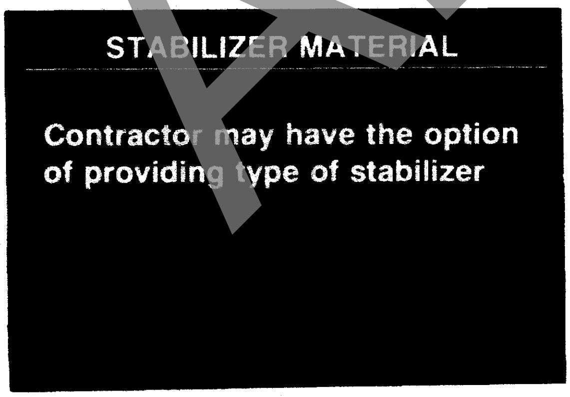
Stabilized Bases



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.



The primary purpose of the stabilizer is to provide stability of the permeable base during the construction phase. A stabilizer should be considered when the maintenance of traffic control requires construction equipment to drive over the permeable base.

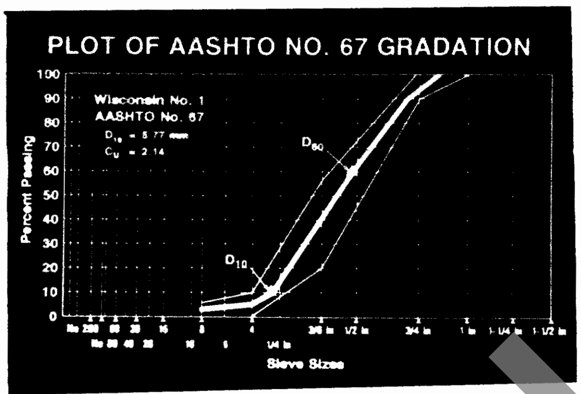


FHWA recommends that the contractor have the option to use either type of stabilized material. Some concrete paving contractors will want to perform and control the work themselves and utilize cement as a stabilizer. Other contractors will want to use a asphalt stabilized permeable base. By giving the contractor an option, we expect more contractors to bid on the project.

AASHTO NO. 67 GRADATION

Sieve Size	Percent Passing
1"	100
3/4"	90-100
3/8"	20-55
No. 4	0-10
No. 8	0-5

The AASHTO No. 67 gradation is now being used by several states.



The AASHTO No. 67 stone gradation is plotted on the gradation chart. The effective size is 5.77 mm and the coefficient of uniformity is 2.14.

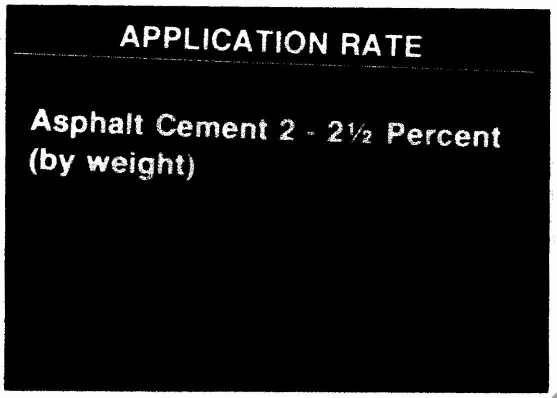
Since the coefficient of uniformity is less than 4, a stabilizer should be used with this gradation.

STABILIZATION

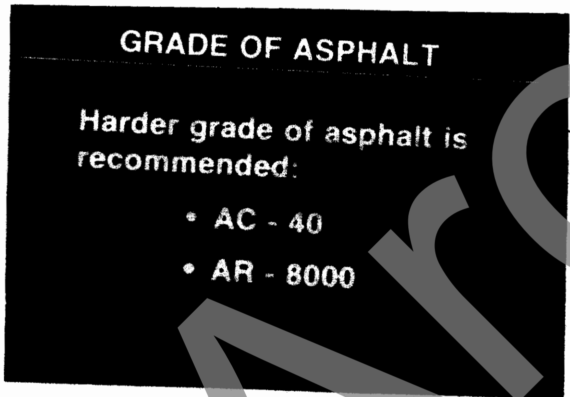
Stabilization is not a substitute for good quality aggregates

Stabilization is not a substitute for using quality crushed stone as an aggregate. Stabilization is used where the coefficient of permeability (k) required is greater than the k that an unstabilized permeable base can provide.

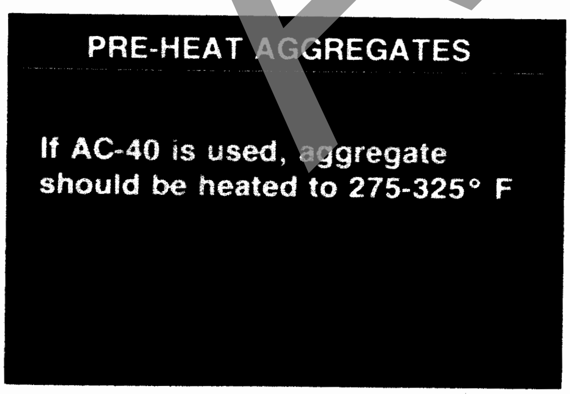
Asphalt Stabilized



Asphalt cement is added to the mix at 2 to 2.5 percent by weight of the mix.



A harder asphalt cement is recommended. We are talking about AC-40 grade or AR-8000. This should provide the stability necessary for construction traffic.



If an AC-40 is used, the aggregates should be preheated to 275 to 325 °F.

Whatever the asphalt cement, the temperature-viscosity curve for the particular asphalt cement is used to determine the mixing temperature.

HOPPER TEMPERATURE

200 - 250° F

The mix temperature that we are looking for at the paver hopper is 200 - 250 °F.

It is recommended that the asphalt stabilized permeable base be laid at temperatures of not less than 200 °F.

COMPACTION TEMPERATURE

Cool to 150° F
Finish Before 100° F

The asphalt stabilized permeable base should be compacted after the has cooled to 150 °F and prior to cooling to 100 °F.

COMPACTION OF ASPHALT STABILIZED BASE

- 1 to 3 passes of 5-10 ton steel wheel roller
- No vibratory rollers

One to 3 passes of an 5 to 10 ton steel wheeled roller in the static mode is sufficient compaction for an asphalt stabilized permeable base.

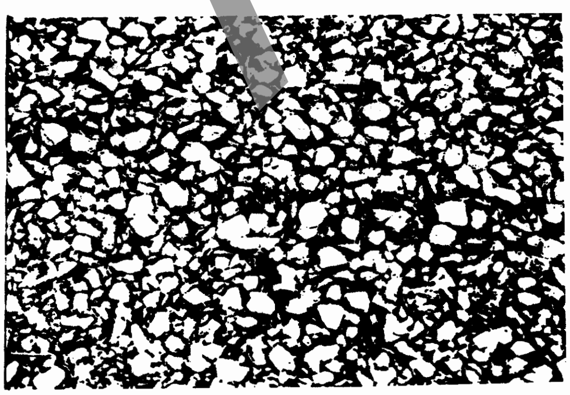
Here is a slide of permeable base placement on top of a geotextile. The geotextile should be free of wrinkles and tears. Notice the excess material at the joint. This will have to be cleaned up before bringing the next section. Perhaps the contractor should have constructed a paper joint.

Another item of interest is to notice that this State chose to use a different material in the edge drain trench. It is important to remember that the coefficient of permeability of the material in the edgedrain trench should meet or exceed the coefficient of permeability of the stabilized base.

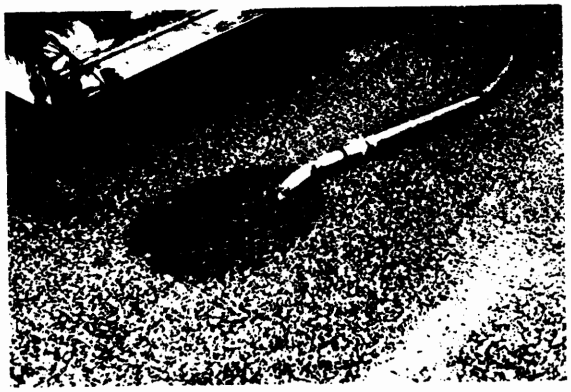
Some States feel that by placing asphalt stabilized base in the edgedrain trench would melt the PVC pipe.

Here is a slide of a permeable base placed in sections with the concrete pavement. We need to remember when developing maintenance of traffic plans to leave enough room to splice the geotextile for placement of the next lane.

Shot of hand work placement of permeable base. This is going to be hard to compact because of the tie bars. Why couldn't we have extended the permeable base another 4 feet to eliminate this problem. It is important to remember construction procedures during the phasing of maintenance of traffic plans.



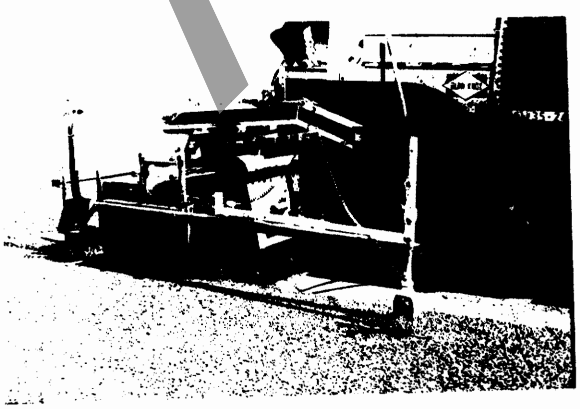
A close up shot of the permeable base. Notice the coarse gradation of the No. 57 stone.



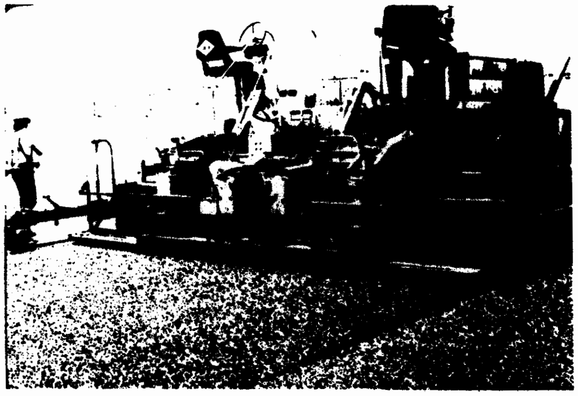
This slide was taken at the Wisconsin Open House. Notice the small spread of water on the surface of the permeable base from the hose of the water truck. The water is being absorbed by the permeable base.

Here is the outlet pipe for that section of the permeable base with the water truck. The flow out of the pipe is almost the same as that out of the water truck hose. The flow out of the pipe was almost instantaneously.

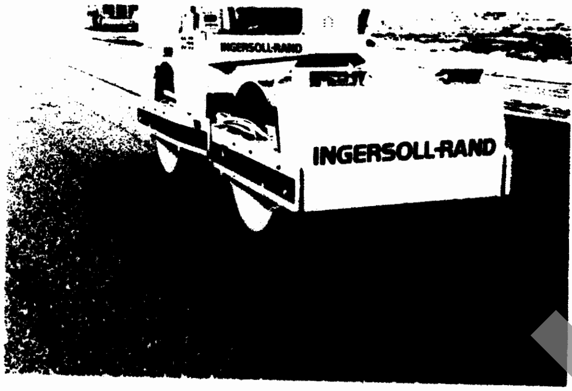
Permeable base is placed with the same equipment as conventional hot mix asphalt.



A joint matcher is used to place a butt joint as a previously placed lane. Notice that we are not expecting much roll down during compaction.

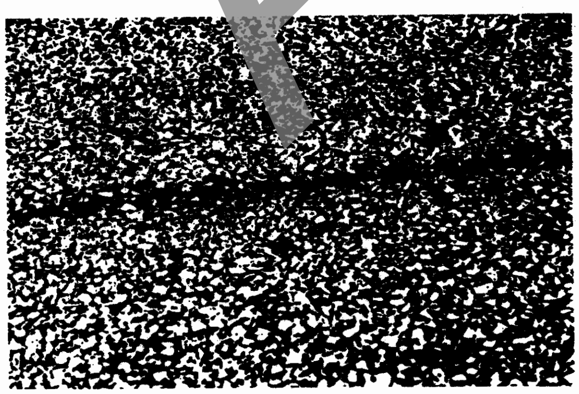


A better slide of the mat behind the screed. Not much difference between the elevation of the hot mat and the compacted mat.

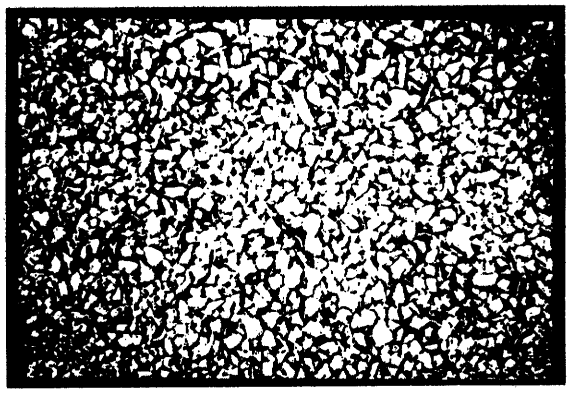


Compaction is obtained with one to three passes of a 5 to 10 ton roller. The roller should either be a static or a vibratory in the static mode.

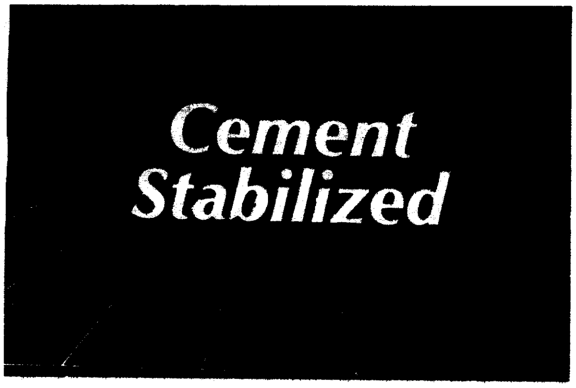
There is a minimal amount of roll down during compaction. We are not expecting a lot of compaction. We just want to seat the aggregate.



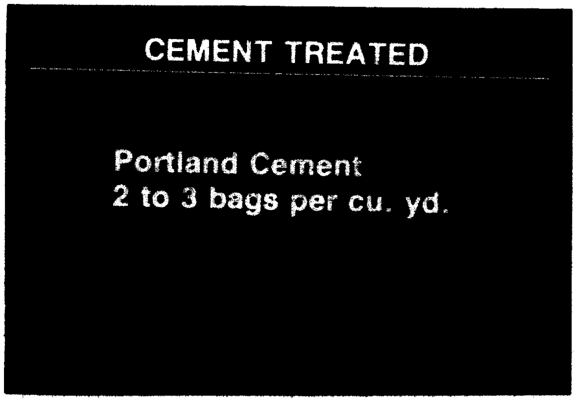
Texture of the permeable base.



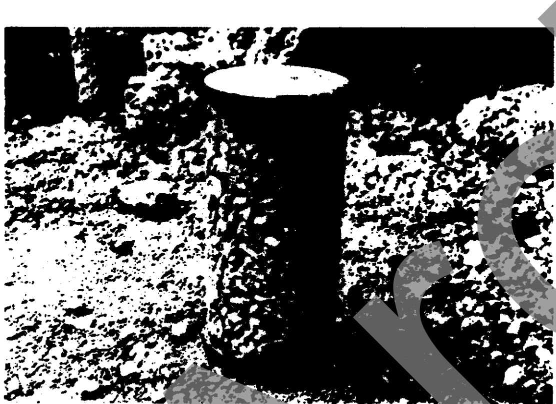
Slide of another permeable base.



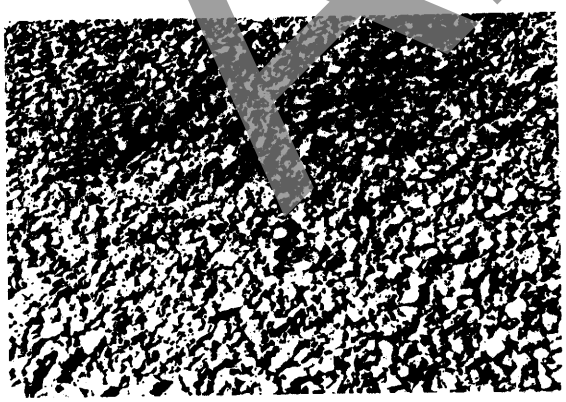
Portland cement is also used by some states as a stabilizer.



Portland cement is added at a rate of 2 to 3 bags per cubic yard of mix.



This is a test specimen of a cement stabilized permeable base. What we are looking for is enough cement to hold the aggregate together.



This is a slide of the cement stabilized permeable base in-place.

COMPACTION OF CEMENT STABILIZED BASE

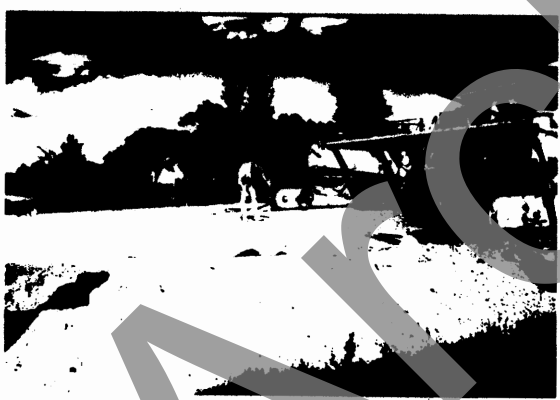
Vibratory screeds set base material

For compacting cement stabilized permeable bases, a number of states have had good success in using only vibrating screeds and plates on the paving machines.

CURING

- Polyethylene Sheeting
- Fine Mist Cure

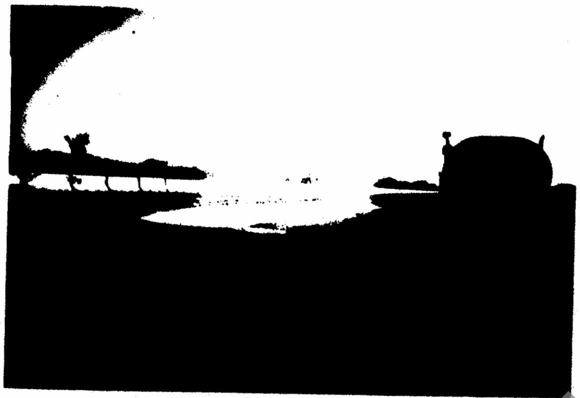
The curing of cement stabilized permeable bases is not a defined practice. One method is to cover the permeable base with polyethylene sheeting for 3 to 5 days. Another method is to apply a fine water mist cure to cement stabilized base several times a day after the base is placed. Sometimes no curing was performed at all. A SHA may want to construct a test strip to determine which curing method to employ as well as a compaction method.



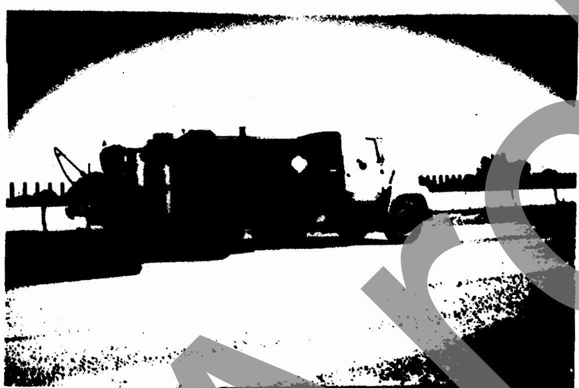
When sheeting is used for curing we always have to overcome the constant problem with keeping the sheeting down.

One method is to take excess subgrade and place it directly on the sheeting.

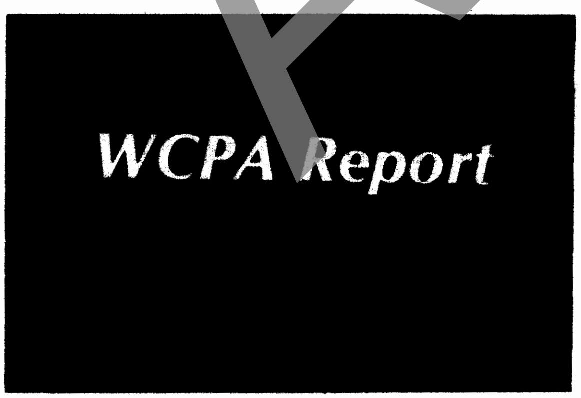
Another slide of the same project showing the curing of the permeable base. Prior to beginning placement operations, the sheeting and grade material must be removed. This is material and labor intensive work. Is this additional cost providing any benefit? It is not known.



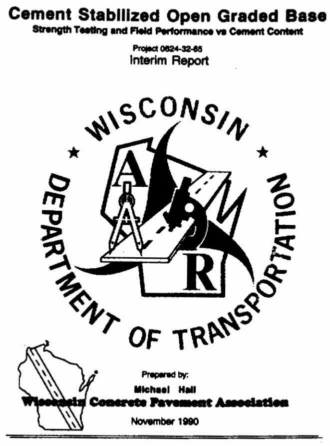
Water Curing - Oklahoma Photo



Asphalt Emulsion - Oklahoma Photo
An asphalt emulsion is being placed on top of the permeable base to serve as a demarkation line when cores are taken to determine pavement thickness.



The Wisconsin Concrete Pavement Association, in cooperation with James Cape and Sons, WISDOT and the FHWA conducted a study using cement stabilized permeable base underneath a concrete pavement.


Cement Stabilized Open Graded Base
Strength Testing and Field Performance vs Cement Content
Project 0624-32-65
Interim Report

Prepared by:
Michael Hall
Wisconsin Concrete Pavement Association
November 1990

The objectives of this study were:

Assess the feasibility of using standard concrete testing methodologies to measure the strength of open graded materials.

Determine performance under construction loading.

Examine correlation between cement content and the level of performance.

Effectiveness of curing

WCPA REPORT
CONCLUSIONS

- Cement Content
- Trucking Volume
- Stability of Underlying Layers
- Separation of Cement Paste
- Surface Irregularities

The report concludes that the performance of the cement stabilized open graded base depends on:

- Cement content.
- Trucking volume.
- Stability of underlying layers.
- Separation of cement paste from the aggregate.
- Surface Irregularities.

WATER/CEMENT RATIO

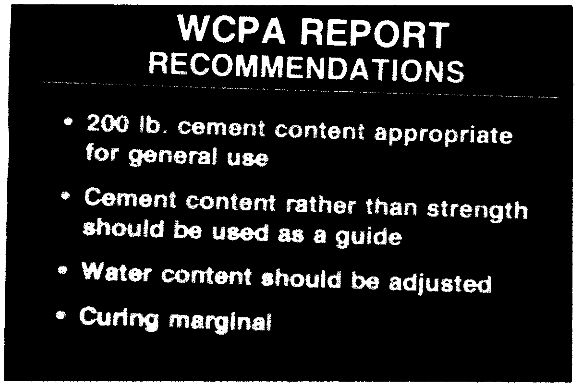
- Higher water/cement ratios may encourage cement paste to flow to points of aggregate contact

It also concludes that higher water/cement ratios may encourage cement paste to flow to points of aggregate contact.

WATER/CEMENT RATIO

- Contractor determines water/cement ratio based on subjective assessment

The report does not establish a maximum water/cement ratio. Instead, it recommends that contractor determine the water/cement ratio based on a subjective assessment of the workability of the mix.

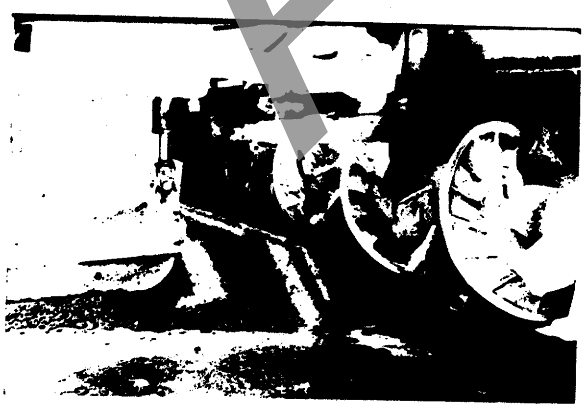


Other recommendations include:

- Mixes with 200 pounds of cement content are appropriate for general use.
- The cement content rather than strength should be used as a guide.
- Water content should be adjusted to control segregation of the mix.
- Curing should be investigated to determine if curing can be eliminated without substantial loss of performance under actual job conditions.

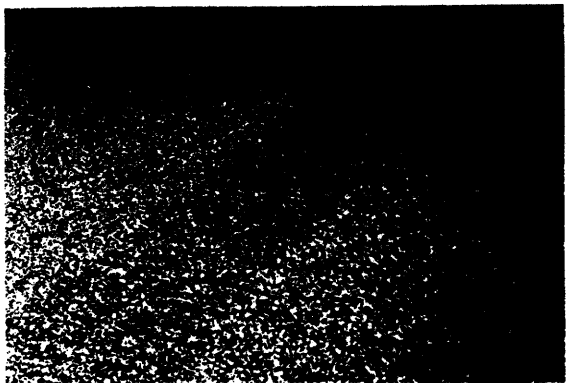
Does the concrete pavement penetrate a permeable base? This is a permeable base taken from a core through the pavement and the permeable base. The core of the permeable base has been split into tow pieces. The part on the left hand side shows penetration of mortar in the top part of the permeable base. Notice the voids are more closed up than the part on the right hand side.

Placing cement stabilized permeable base over subgrade. Notice the rutting problem with the underlying layer. We may have a problem with support for construction.



CMI trimmer has augers to move and windrow excess permeable base.

A vibrating screed provides the compaction of the cement stabilized permeable base.



There is some concern with the track marks from the paver.

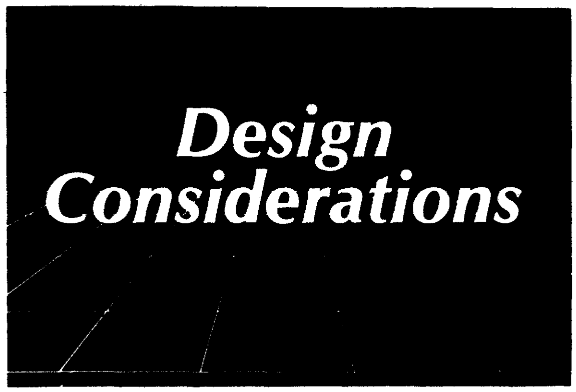
This contractor elected to use a vibrating plate to eliminate the track marks.

A water truck was opened up to see if the cement stabilized base could dissipate the water.

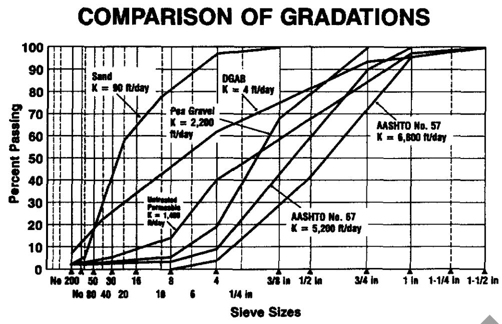
The water appears at the edge of the cement stabilized base. Edgedrains have not been placed yet.

A little while later you can see more of the water has move to the edge of the permeable base.

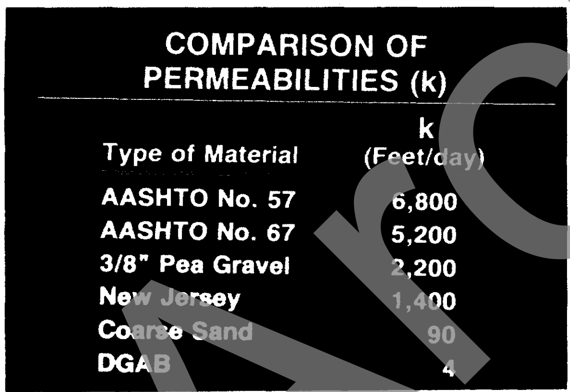
Notice the more open texture of the cement stabilized base. Construction traffic needs to be limited to eliminate contamination.



Design Considerations

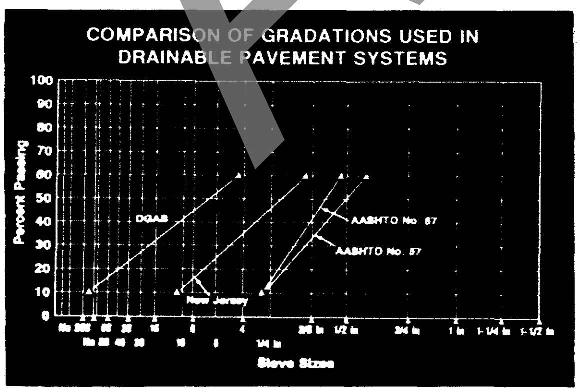


This is a plot of the different gradations used in the permeability model shown yesterday. This slide is shown on page 96 of the student workbook. The coefficient of permeability is also shown for each gradation. Notice how the coefficient of permeability increases as the gradation moves to the right of the graph.



We used the Falling Head Permeability test to measure the coefficient of permeability of each of the materials in the Demonstration Model.

AASHTO No. 57	6800 ft/day
AASHTO No. 67	5200 ft/day
3/8" Pea Gravel	2200 ft/day
NJDOT unstabilized	1400 ft/day
Sand	90 ft/day
DGAB	4 ft/day

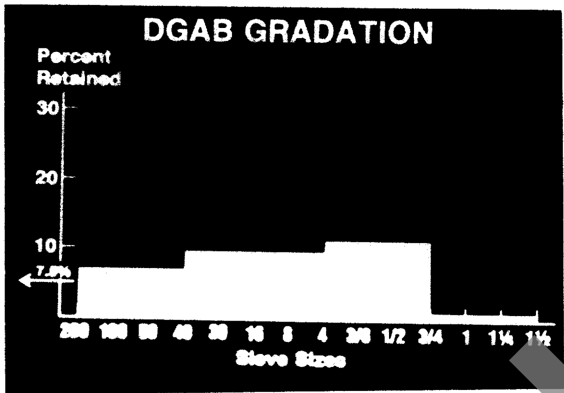


This is a plot of the D_{10} and D_{10} for each gradation of the different materials. If you recall the coefficient of each material, you will notice the faster draining materials fall to the right of the gradation chart and the order would follow the plot of effective size D_{10} and D_{60}. As the effective size increases, the coefficient of permeability also increases, and the time to drain we observed yesterday decreases.

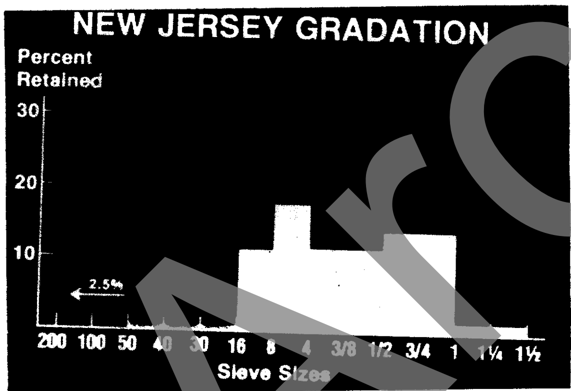
COMPARISON OF D_{10} & C_U

Type of Material	D_{10} (mm)	C_U
DGAB	0.10	45.97
New Jersey	1.90	4.68
AASHTO No. 67	5.77	2.14
AASHTO No. 57	5.98	2.54

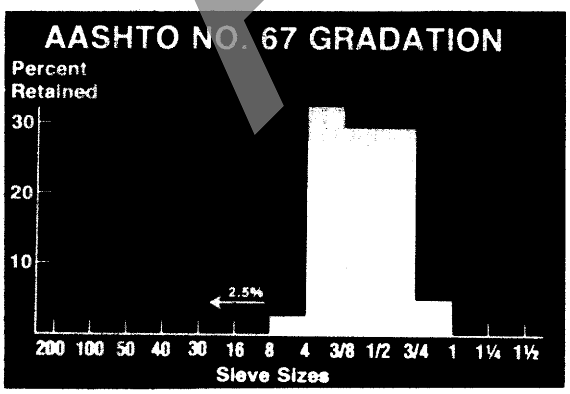
The table provides a comparison of the effective size and coefficient of uniformity of each material. As the effective size increases, the coefficient of uniformity decreases and the material becomes more open.



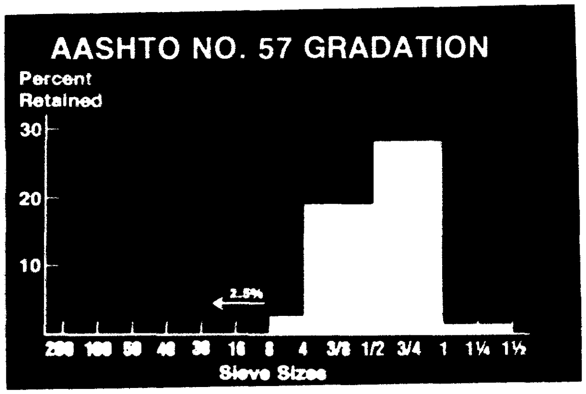
Another way to look a the different gradations is plot percent retained on the different sieves by a bar graph. This is the plot of a dense graded aggregate base. Notice the uniformity of the percent retained on each sieve. There is not much variation. 7.5% of the material passes the No. 200 sieve.



The percent retained for the New Jersey DOT unstabilized permeable base. Notice that there is relatively uniform distribution retained on the No. 16 sieve through the 3/4" sieve. Only 2.5% passes the No. 50 sieve.



The percent retained for the AASHTO No. 67 stone. The majority of the material is between the 1 inch and No. 4 sieves. Only 2. 5 percent of the material passes the No. 8 sieve. The maximum size of the gradation is 1 inch.



The percent retained for the AASHTO No. 57 stone. This gradation has the majority of the gradation is in the 3/4 inch to 1 inch material. The rest of the gradation is made up with 3/8 inch through 1/2. There is only 2.5 percent material passing the No. 8 sieve. The maximum size of this gradation is 1 1/2 inches.

BASE THICKNESS

- Minimum Thickness - 4 inches
- Based on Construction Considerations

The recommended minimum permeable base thickness 4 inches. This thickness should be adequate to overcome any construction variances and provide an adequate conduit to transmit the water to the edgedrain.

CONTROL STRIP

- FHWA recommends use of a control strip
- Test combination of aggregate materials and construction practices

We recommend a control strip be constructed at the beginning of construction so the combination of aggregate materials and construction practices be tested, and adjusted if necessary.

CONTROL STRIP

- Minimum length - 500 ft
- Becomes part of finished roadway (if acceptable)

The minimum length of test strip is 500 feet. If the test strip is acceptable, the it should become a part of finished construction. What we are looking for during placement is stability, number of passes, and permeability.

CONSTRUCTION CONSIDERATIONS

- Quality
  - Aggregates
  - Construction
- Proper Application Rates
- Difficult to trim surface
- Compaction

(continued)

The subgrade and the aggregate separator layer should be properly constructed so that there is a stable working platform for placing the permeable base. The permeable base is not a substitute for a strong uniform subgrade.

Quality crushed stone aggregates is the single most important factor for the stability of the base. If a stabilizer is specified, the application rate should meet the specifications. It is recommended that the contractor be provided the option to choose the stabilizer.

Compaction of permeable bases should be in accordance with the specifications. Over compaction can result in crushing and degradation of the aggregate.

CONSTRUCTION CONSIDERATIONS

(continued)

- Construction Traffic
- Tracked Pavers
- Maintain Minimum Slope
- Incentive/Disincentive Ride Requirements

Construction traffic on the completed permeable base should be kept to a minimum. Haul lengths should be kept to a minimum length. Truck speeds should be kept low and turning as well as stopping and starting motions should be smooth.

A minimum resultant slope of 2 percent is recommended wherever possible.

THICKNESS

Pavement drainage is not a substitute for pavement thickness or a strong subgrade

A point we really want to emphasize it that pavement drainage is not a substitute for pavement thickness or a strong subgrade.

If you have run any sensitivity analysis of the drainage coefficient with the AASHTO Guide for Design of Pavement Structures, you will notice that the equation says you can reduce thickness due to improved drainage or you can increase thickness to overcome poor drainage. We know from actual in-place performance that poor drainage will lead to pumping and faulting and is not dependent on slab thickness.

Therefore, the FHWA recommends that pavement drainage should be considered in all designs. If poor drainage conditions exist, these condition should be corrected. A drainage factor of 1.0 should be used with the AASHTO Guide to determine the pavement structure required.

Separator Layer

A separator layer must be provided between the permeable base and the subbase/subgrade to keep soil particles from contaminating the permeable base.

TYPES OF SEPARATOR LAYER

- Aggregate
- Geotextile

The are two types of separator layers.

- Aggregate separator layer.
- Geotextile separator layer.

A separator layer is not a substitute for a strong subgrade.

Aggregate Separator Layer

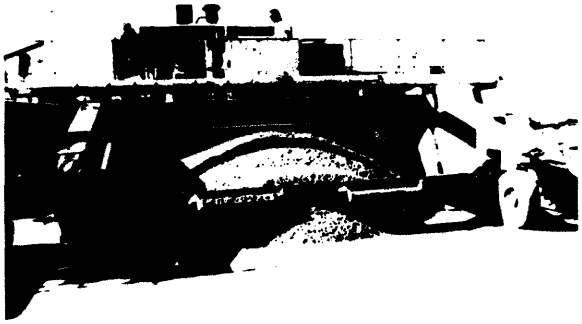
Aggregate separator layer.

AGGREGATE SEPARATOR LAYER

- Stability
- Filtration
- Permeability

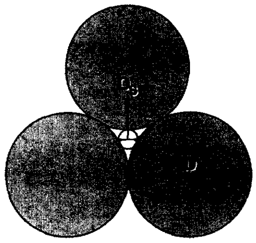
The aggregate separator layer must perform several important functions:

- The aggregate separator layer must be strong enough to provide a stable working platform for constructing the permeable base.
- The gradation of the aggregate separator layer must be carefully selected to prevent fines from pumping up from the subgrade into the permeable base.
- The aggregate separator layer should have a low permeability. The layer should act as a shield to deflect water over to the edgedrain.



Placing permeable base over an aggregate separator layer.

FILTRATION REQUIREMENT



$D = 6.46\ D_S$

In theory, a small spherical particle will be retained by larger spherical particles until the diameter of the smaller particle is 6.46 times smaller than the diameter of the larger particles. This theory gives us two gradation requirements for aggregate separator layer to prevent migration of fines from the subgrade.

FILTRATION REQUIREMENT

D_{15} Separator $\leq$ 5 D_{85} Subgrade

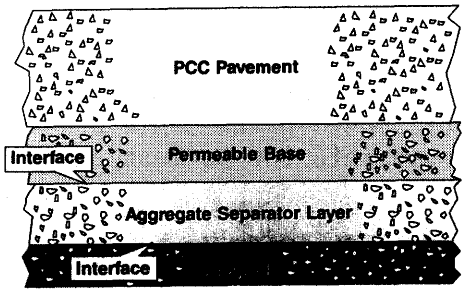
D_{15} (Separator layer) $\leq$ 5 x D_{85} (Subgrade) is a filtration requirement. By limiting the D_{15} size of the aggregate separator layer to less than five times the D_{85} size of the subgrade, the larger soil particles of the subgrade will be retained, allowing soil bridging action to begin. We want to retain the D_{85} of the subgrade with the aggregate separator layer. The D_{15} of the aggregate layer provides the filtration of the subgrade.

UNIFORMITY REQUIREMENT

D_{50} Separator $\leq$ 25 D_{50} Subgrade

D_{50} (Separator layer) $\leq$ 25 x D_{50} (Subgrade) is an uniformity requirement. By limiting the D_{50} size of the aggregate separator to less 25 times the D_{50} size of the subgrade, the gradation curves will be kept in balance.

INTERFACE DESIGN



This is the interface between the subgrade and base.

SEPARATOR/SUBGRADE INTERFACE

D_{15} Separator $\leq$ 5 D_{85} Subgrade

D_{50} Separator $\leq$ 25 D_{50} Subgrade

At the separator layer/subgrade interface, the D_{15} of the aggregate separator layer should be less than or equal to 5 times the D_{85} of the subgrade for filtration.

The D_{50} of the separator layer should also be less than or equal to 25 times D_{50} of the subgrade.

BASE/SEPARATOR INTERFACE

D_{15} Base $\leq$ 5 D_{85} Separator

D_{50} Base $\leq$ 25 D_{50} Separator

At the separator layer/subgrade interface, the D_{15} of the aggregate separator layer should be less than or equal to 5 times the D_{85} of the subgrade for filtration.

The D_{50} of the separator layer should also be less than or equal to 25 times D_{50} of the subgrade.

COEFFICIENT OF UNIFORMITY (C_U)

C_U should be greater than 20 and preferably in the vicinity of 40

The coefficient of uniformity C_U for the dense graded aggregate base should be greater than 20 preferably around 40. This will ensure that the dense graded aggregate base is well-graded.

FINES

FHWA recommends maximum percent fines not exceed 12%

The maximum amount of material passing the No. 200 sieve for dense graded aggregate bases should be limited to 12 percent. This should minimize the amount of fines in the dense graded aggregate base that pump into the permeable base.

SEPARATOR LAYER

- Class C Aggregate AASHTO M 283-83
- L.A. Abrasion Wear Not Exceed 50 Percent

The separator layer should consist of durable, crushed, angular aggregate material. The aggregate should meet the requirements for AASHTO M 283-83 Class C Coarse Aggregate. The L.A. Abrasion Wear should not exceed 50 percent.

SOUNDNESS

- AASHTO T 104-86
- Sodium Sulfate - 12%
  Magnesium Sulfate - 18%

The soundness percent loss should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests following AASHTO T 104-86.

COMPACTION

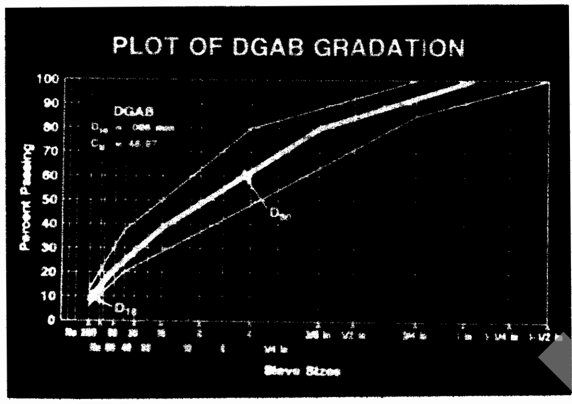
- 95% of Maximum Density
- AASHTO T 180-90

The dense graded aggregate base should be compacted to 95 percent of its maximum density, determined by AASHTO T 180-90.

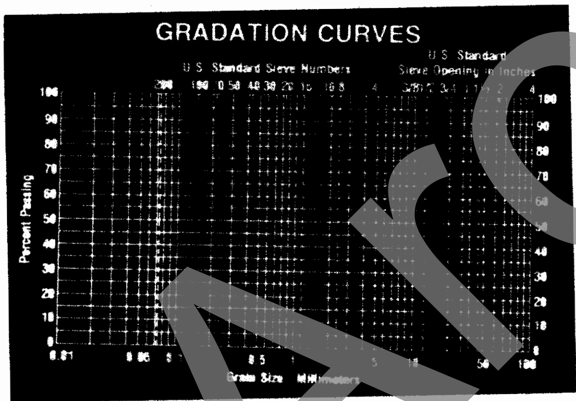
DGAB

Sieve Size	Percent Passing
1-1/2"	100
3/4"	85-100
No. 4	50-80
No. 40	20-35
No. 200	5-12

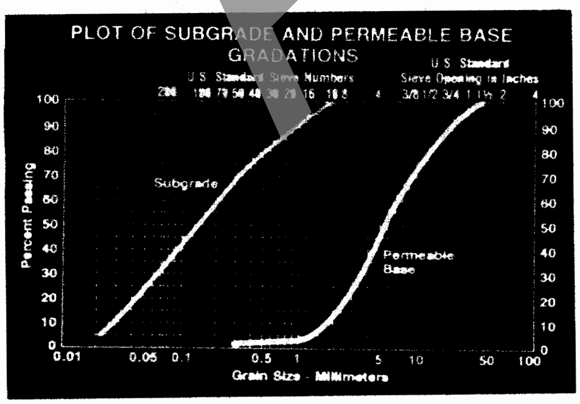
A typical dense graded aggregate base gradation in a table.



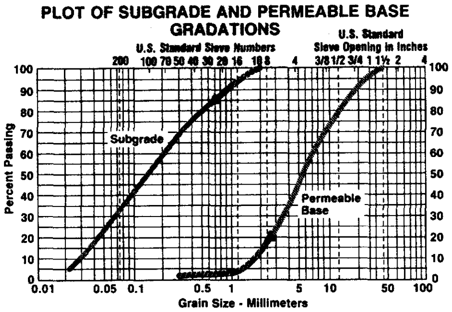
The dense grade aggregate base plotted on the .45 power gradation chart. The effective size (D_{10}) is 0.098 mm and the coefficient of uniformity (C_u) is 45.97, which is around 40 as recommended. Note that gradation band shows a range of 5 to 12 percent passing the number 200 sieve which meets the fines criteria.



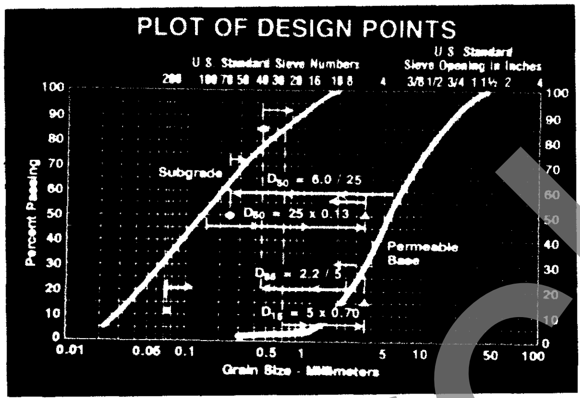
Blank gradation chart.



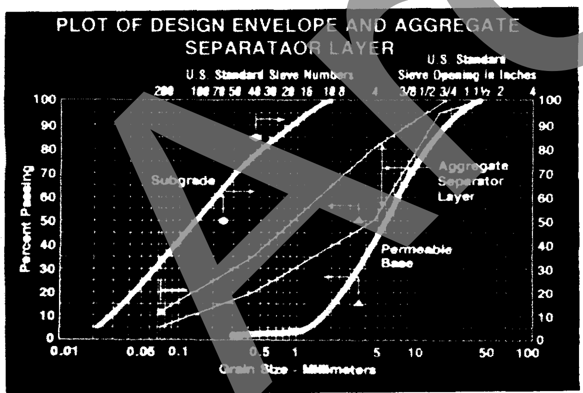
The gradation for a given subgrade and permeable base are plotted on the gradation chart. The chart is used to determine the D_{50} and D_{85} of the subgrade and the D_{15} and D_{50} of the permeable base. The gradation of the aggregate separator layer will fall in between the two gradations. Plotting these points is the initial step in evaluating filtration and uniformity requirement equations.



Lets look at the subgrade/dense graded aggregate base separator layer first. We determine the D_{85} of the subgrade by moving horizontally along the 85 percent passing line until we intercept the subgrade gradation line. Move vertically and determine the grain size. This grain size (0.7) is multiplied by 5. Draw a vertical line from the calculated grain size (3.5). The D_{15} of the aggregate separator layer must be less than or to the left of this grain size. Similarly, move along the 50 percent passing line until the subgrade gradation is intercepted. Read the D_{50} (0.13) and multiply by 25. Draw a vertical line at this grain size (3.25). The D_{50} of the aggregate separator layer must be less than, or to the left, of this grain size. We have just plotted the filtration and uniformity requirements of the subgrade and aggregate separator interface.



We would have to evaluate the permeable base and aggregate separator layer interface. The D_{15} of the permeable base is determined. The 15 percent passing extended to the permeable base gradation. This grain size (2.2) is divided by 5 (0.44). The D_{85} of the aggregate separator layer must be greater than, or to the right of, this grain size. The D_{50} of the permeable base is determined (6.0) and divided by 25 (0.24). The D_{50} of the aggregate separator layer must be greater than, or to the right, of this grain size.



This chart has the points superimposed. The dense aggregate base gradation would have to fall in the envelope to perform its function.

A dense graded base gradation is now plotted. Notice that the bottom of the band of the dense graded aggregate base outside of the 25 times the D_{50} subgrade line. Not every single dense graded base gradation will fall within the required envelope. This example may not be a bad dense graded base separator layer if the coefficient of uniformity and percent passing the number 200 sieves for the dense graded aggregate rules are not violated.

LAYER THICKNESS

- Minimum Thickness - 4 inches
- Based on Construction Considerations

A minimum thickness of 4 inches is recommended for the aggregate separator layer based on construction considerations. Greater thickness can be placed if required in the structural evaluation.

CONSTRUCTION CONSIDERATIONS

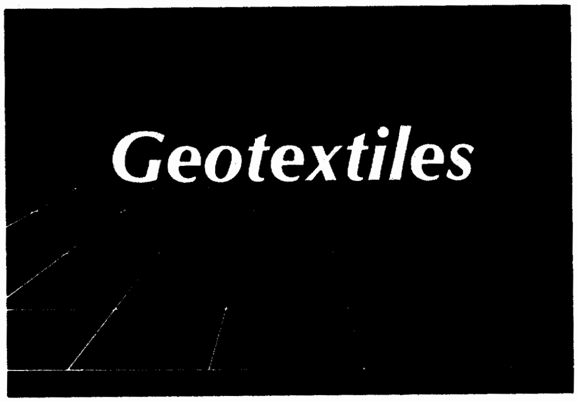
- Quality of Aggregates
- Compaction

Quality of aggregates and proper compaction are the keys to a functional separator layer. This layer is necessary to provide a stable platform for placing the permeable base and concrete pavement and to prevent future contamination of the permeable base by fine silts and clay particles which could choke the permeable base and reduce the effective drainage.

SEPARATOR LAYER

- Required to keep fines from migrating into permeable base
- Recommended dense graded aggregate base

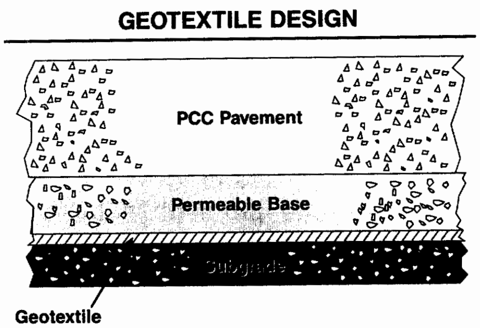
The aggregate separator layer is required to keep fines from contaminating the permeable base. A dense aggregate base course is recommended because it provides additional structure. The dense graded aggregate base course should consist of durable, crushed, angular, aggregate material. The aggregate should have good mechanical interlock.



GEOTEXTILES

Geotextiles can also be used for the separation layer.

Does your State use geotextiles?



The typical section for the concrete pavement remains the same. The geotextile is placed in between the permeable base and the subgrade soil.

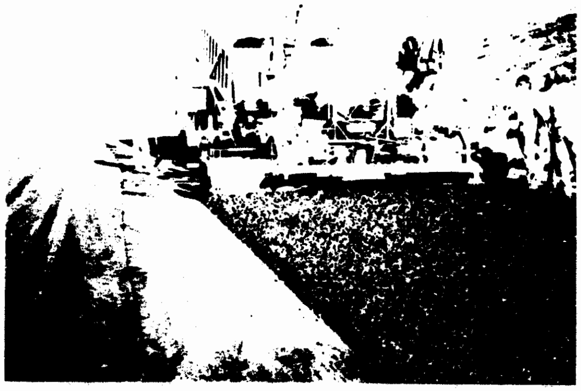
The geotextile is also used to wrap the trench and separate the subgrade soil and the trench backfill.

The trench has been backfilled and the truck is delivering permeable base to the spreader.

One thing we must consider is that the geotextile must be strong enough to withstand construction traffic. For example, when the truck runs over the aggregate spillage, the geotextile must be puncture resistant.

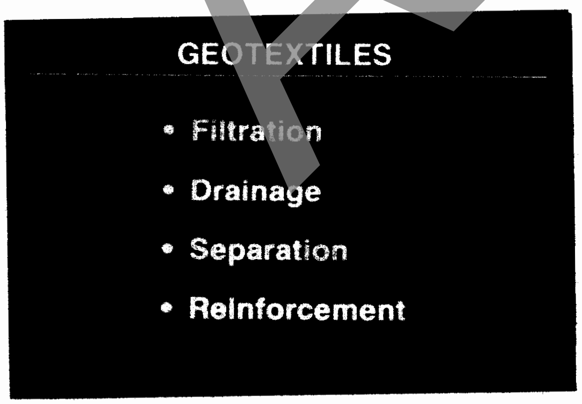
We also have transverse and longitudinal seams with geotextiles.

One thing to notice here, it appears that not enough geotextile was placed on the outside of the trench. We want extra geotextile so that we can overlap the permeable base with the geotextile.



We are placing asphalt treated permeable base on the geotextile. One thing to remember during design is the heat resistance of the geotextile. I would also be concerned with heating the paver screed on the geotextile.

Rolling the permeable base can cause particles to reorient during rolling. We need to be aware of this during the design of the geotextile.



Geotextiles can be designed to perform the following functions:

- Filtration
- Drainage
- Separation
- Reinforcement

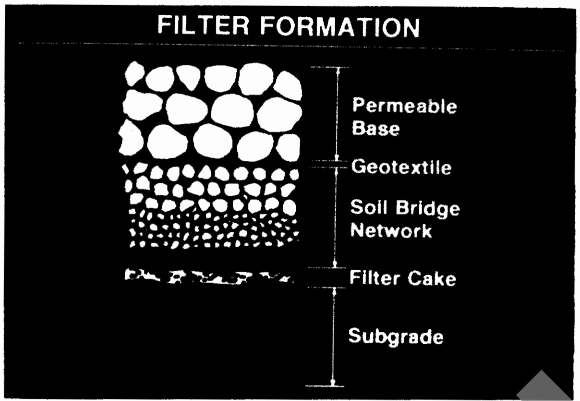
For pavement drainage systems, the purpose that the geotextile must perform is separation. A secondary function should also be filtration.

FILTRATION CONCEPTS

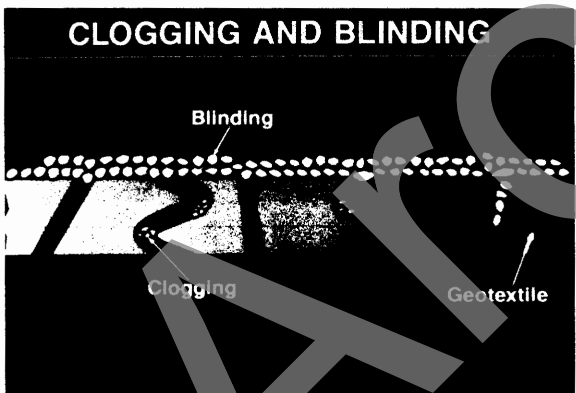
- Retain Larger Particles
- Pass Smaller Particles
- Large Number of Openings

The concepts for geotextiles for separation are:

- the geotextile should retain the large particles of the subgrade soil.
- small particles should be able to pass through the geotextile so it does not clog.
- The geotextile should have a large number of openings so that if an opening clogs, there will other openings that will permit water to move.



In most cases, a small amount of fines will pass through the geotextile into the permeable base. This starts the formation of a filter zone adjacent to the geotextile. As larger soil particles are retained by the geotextile, a bridging action occurs creating a zone called the "soil bridge network". Immediately behind this zone is another zone where the finer soil particles are trapped. This zone is called a "filter cake" and has a lower permeability. In the last zone the subgrade particles will be undisturbed.



Clogging and blinding of the geotextile are two potential problems.

CLOGGING AND BLINDING

Clogging

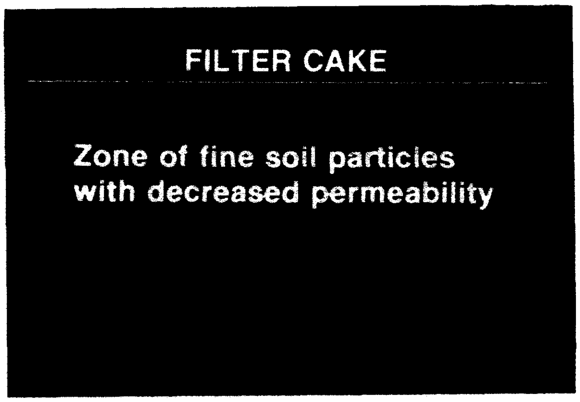
- Soil particles trapped in openings

Blinding

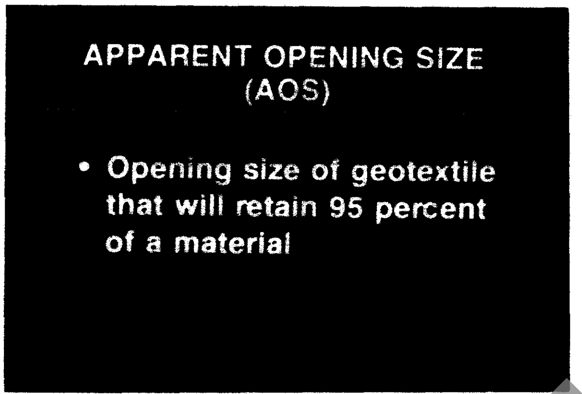
- Soil particles coat fabric surface

Clogging of the geotextile is when the soil particle becomes entrapped in the geotextile preventing the flow of water through it.

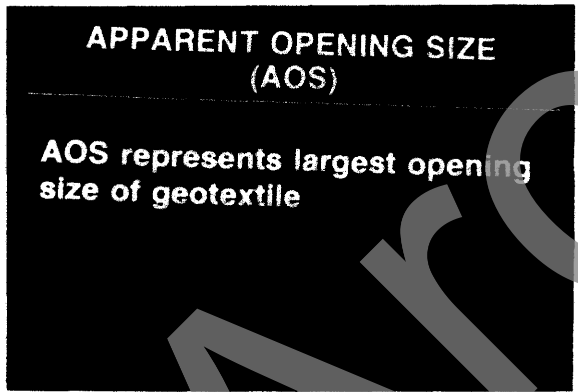
Blinding of the geotextile is when finer particles build up on the outside of the geotextile preventing the flow of moisture through the geotextile.



The filter cake is the last layer in the soil bridging network. It consists of the zone where all the finer soil particles are trapped. The area has a lower permeability than the subgrade soil.



The apparent opening size (AOS) of the geotextile is the U.S. standard sieve size number that will retain 95 percent of the subgrade soil.



The AOS value is an index test that only identifies the largest opening size of the geotextile.

This sketch illustrates the AOS of different types of geotextiles. This can mean different things depending on the type of material. For a sieve, the openings are square and the same size. For woven geotextiles, the openings are rectangular and the same size. For nonwoven geotextiles, the openings are irregular. Clogging one of these openings may be more critical.

AOS

AOS of a geotextile can be expressed:

- Sieve Number No.70
- O_{95} (millimeters) .212 mm

The AOS of a geotextile is expressed as a standard sieve size. Some people use the term O_{95}. The O_{95} and the AOS define the same property. The O_{95} is the opening size in millimeters.

AOS

ASTM D-4751 Determining Apparent Opening Size of a Geotextile

The opening size is determined by sieving single-size glass beads through the geotextile in accordance with ASTM D-4751. The test is repeated with successive smaller size beads until 5 percent or less, by weight, passes through the geotextile. The AOS number is the sieve size number of the glass balls that 5 percent or less passed.

GEOTEXTILE OPENING SIZES

Sieve Number	Sieve Opening (mm)
30	0.600
40	0.425
50	0.300
60	0.250
70	0.212
100	0.150
200	0.075

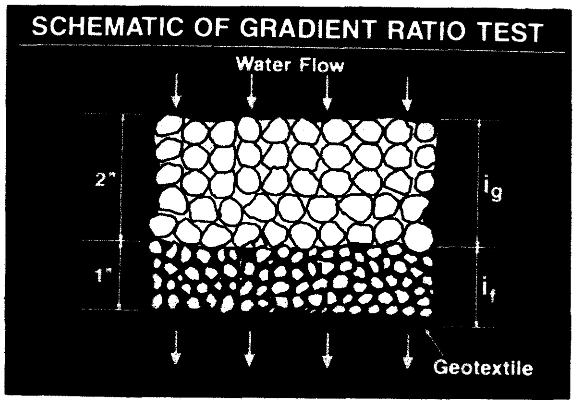
The nomenclature is confusing because the O_{95} and the AOS measure the same property. This table show the sieve size and opening sizes in millimeters. The AOS is the sieve number and the O_{95} is the opening size. I think part of the confusion lies with the fact that as the opening size (O_{95}) decreases as the sieve size (AOS) increases.

GRADIENT RATIO TEST

Gradient ratio test measures the soil/geotextile system's clogging and retention potential

The gradient ratio test is a direct measurement of the soil geotextile system's clogging and retention potential.

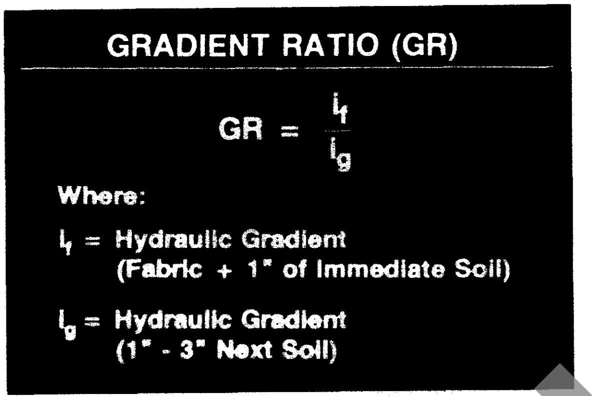
It is a real life performance test developed by the Corps of Engineers.



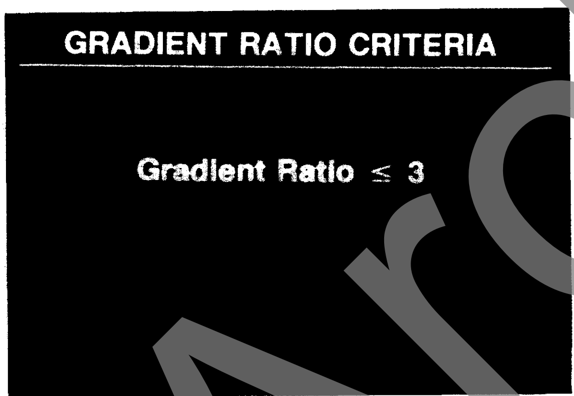
This is a schematic of the gradient ratio test. It consists of determining head loss at two mediums.

I_f - which is the hydraulic gradient of the geotextile and 1 inch of soil adjacent to the geotextile.

I_g - which is the hydraulic gradient of the soil between 1 and 3 inches away from the geotextile.



The gradient ratio test is I_f / I_g. The hydraulic gradient of the geotextile and 1 inch or soil divided by the hydraulic gradient of the soil 1 to 3 inches away from the geotextile. If geotextile clogs, the head loss at this point will increase.



The Corps of Engineers recommends that the hydraulic gradient ratio is less than or equal to 3. To prevent against clogging.

Geotextile Selection

Geotextile Selection -

The selection of geotextiles should be based on performance criteria for its intended function.

TYPES OF GEOTEXTILES

- Knitted
- Woven
- Nonwoven

There are three types of geotextiles. These are:

- Knitted - are seldom used as geotextiles.
- Woven - are made with conventional textile weaving machines.
- Nonwoven - are filaments that extruded or spun together randomly on a conveyor belt and then bonded together.

NONWOVEN PROCESSES

- Heat Bonding
- Chemical Bonding
- Needle Punch

Nonwoven geotextile are manufactured by either:

- Heat Bonding Process - High temperatures melt the filaments, when the filaments cool, the intersections of the different filaments bond together.
- Chemical Bonding Process - A chemical spray is applied to the filaments which causes filaments to bond together at their intersections.
- Needle Punch Process - A barbed needle is punched through the filaments. Little knots are developed causing interlock between entangled filaments. A good example is trying to remove Christmas tree lights from a box. If you pulled on the ends knots will develop in the electrical line.

GEOTEXTILE SELECTION

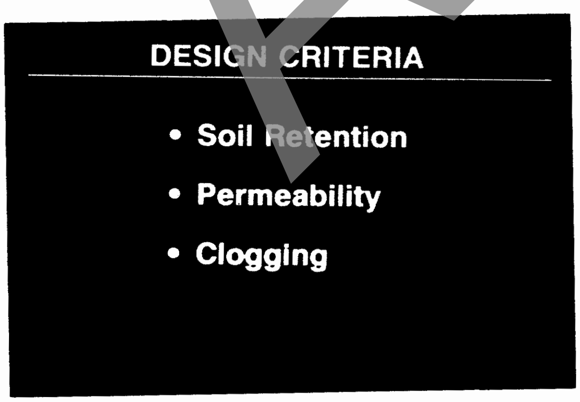
Geotextile Selection should be based on performance rather than type or process

We recommend that geotextiles should be specified based on performance rather than type.

Geotextile Design

Reference Manual is the Geotextile Engineering Manual

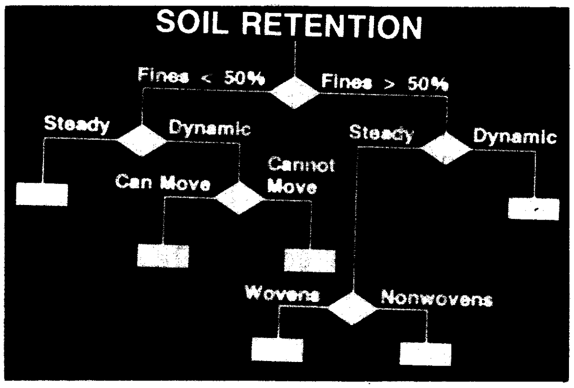
The manual is available through the Federal Highway Administration.



The design criteria for a geotextile follows three categories.

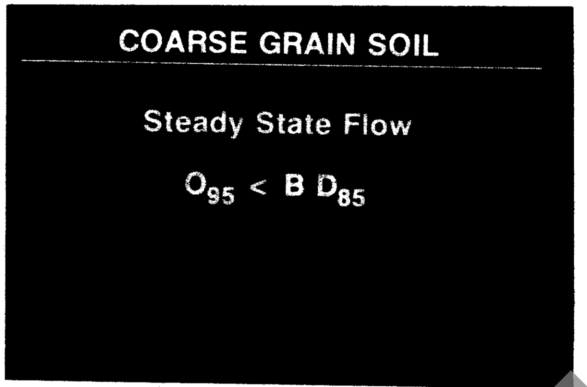
- Soil retention
- Permeability Criteria
- Clogging Criteria

The first step is to size the geotextile based on soil retention requirements. Then permeability and clogging potential are checked.



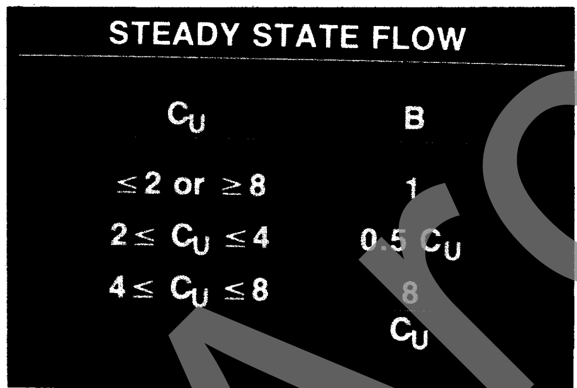
For soil retention, the first step is to determine if the subgrade consists of coarse grain or fine grain soils. This determined by the percent passing the No. 200 sieve.

The flow condition is determined next. Since any reversal in the flow pattern would be so gradual, it is suggested that the steady state flow condition be used.



Coarse grain soils in the steady state flow condition as an example.

The opening size O_{95} of the geotextile is determined by multiplying the D_{85} by the B factor. The coefficient of uniformity of the soil is used to determine the B factor.

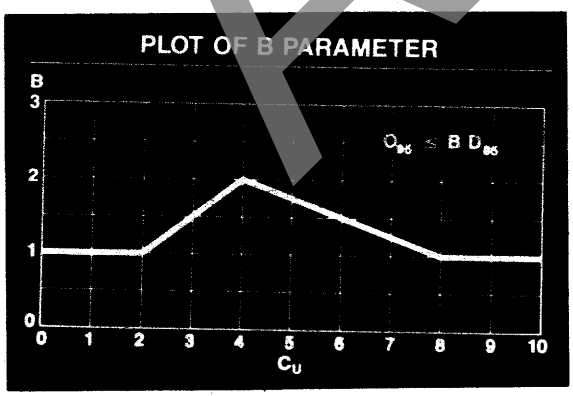


This chart shows the relationship between coefficient of uniformity and the B factor.

When the C_U is less than 2 and greater than 8, the B factor is 1.

When the C_U is greater than 2 and less than 4, the B factor equals 0.5 times C_U

When the C_U is greater than 4 and less than 8, the B factor equals 8 divided by C_U



A plot of the B factor against the coefficient of uniformity is show for a coarse grain soil.

COARSE GRAIN SOIL

Dynamic Flow

$O_{95} \leq D_{15}$ (Move)

$O_{50} \leq 0.5\ D_{85}$ (Cannot Move)

Coarse grain dynamic flow condition. Since the subgrade is confined by the pavement structure, the selection of the "cannot move case" is suggested. The 50 percent opening size O_{50} is less than 0.5 times the D_{85} of the soil.

If the soil can move beneath the geotextile the 95 percent opening size would have to be less than or equal to the D_{15} of the soil.

FINE GRAIN SOILS

Steady State Flow

Woven: $O_{95} \leq D_{85}$

Nonwoven: $O_{95} \leq 1.8\ D_{85}$

Both: AOS No. $\geq$ No. 50 Sieve

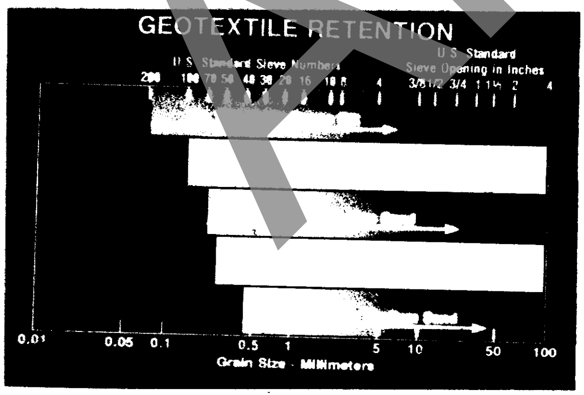
If greater than 50 percent passing the No. 200 sieve, then the soil is classified as a fine grained soil. Again the flow condition is determined. For steady-state flow, if the geotextile is woven, the 95 percent opening size should be less than or equal to D_{85}. If the geotextile is nonwoven, the 95 percent opening size would be less than or equal to 1.8 times the D_{85}. For both cases, the AOS Number has to be greater than or equal to the No. 50 sieve.

FINE GRAIN SOILS

Dynamic Flow

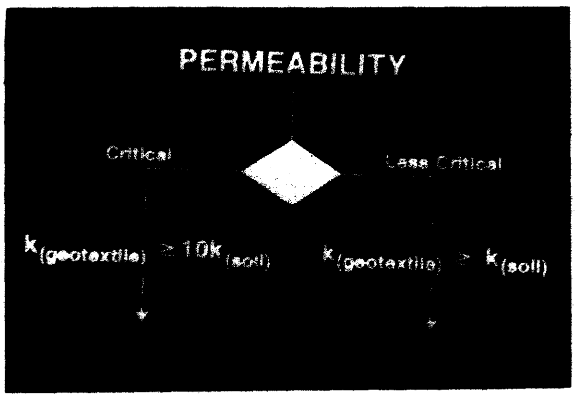
$O_{50} \leq 0.5\ D_{85}$

For fine grain soil, in a dynamic flow condition, the 50 percent opening size is less than or equal to 0.5 the D_{85}.

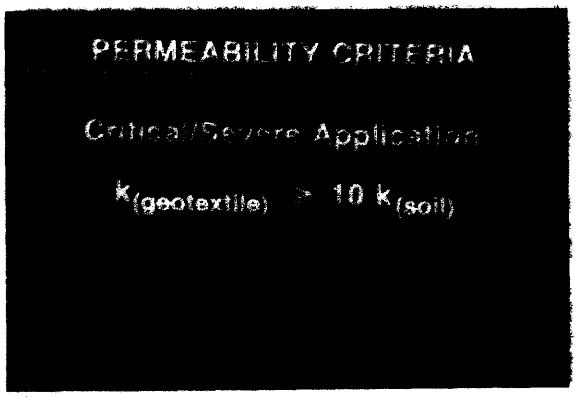


This soil retention chart shows the standard sieve sizes and describes the material that will be retain by that size.

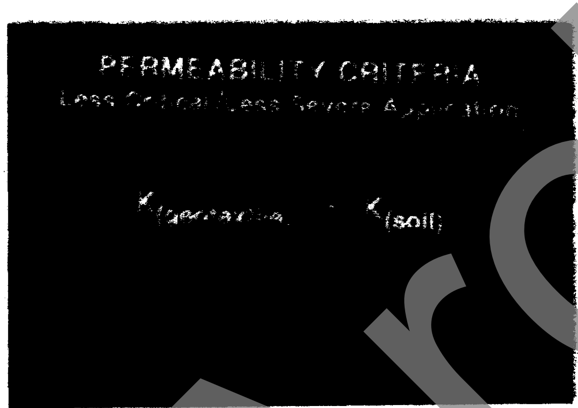
- No. 200 can be expected to retain upper range silts
- No. 100 can be expected to retain lower range sands
- No. 70 can be expected to retain middle range sands
- No. 40 can be expected to retain lower range sands



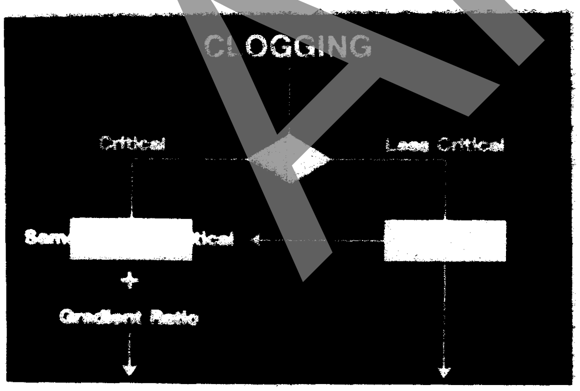
For permeability of the geotextile, a decision must be made to determine if the application is Critical/Severe or Less Critical/Less Severe. An example of a Critical/Severe application is the geotextile separating the subgrade from the edgedrain trench.



For Severe/Critical applications the coefficient of permeability of the geotextile should be greater than or equal to 10 times the coefficient of permeability of the soil.



For Less Critical/Less Severe applications, the coefficient of permeability of the geotextile should be greater than or equal to the coefficient of permeability of the soil.



For Clogging Criteria, again the decision has to be made whether the application is critical/severe or less critical/less severe.

CLOGGING CRITERIA

- Less Critical / Less Severe
- Select Maximum Opening Size (Lowest AOS number)

For clogging criteria in the Less Critical/Less Severe case:

The designer would select the fabric with maximum opening size possible (lowest AOS No.);

ADDITIONAL QUALIFIERS

$O_{95} \geq 3\ D_{15}$

$O_{15} > 3\ D_{15}$

Additional Qualifiers:

The 95 percent opening size is greater than or equal to 3 times the D_{15}.

The 15 percent opening size is greater than or equal to 3 times the D_{15}.

EFFECTIVE OPEN AREA

Woven: Percent Open Area > 4%

Nonwoven: Porosity > 30%

Effective Open Area Qualifiers

Woven fabrics: percent open area is greater than or equal to 4 percent.

Nonwoven fabrics: porosity is greater than or equal to 30 percent.

CLOGGING CRITERIA

- Critical / Severe
- Less Critical Requirements
- Gradient Ratio Test

For clogging in the critical/severe case, The geotextile has to meet the same criteria as the Less Critical/Less Severe application, plus meet the Gradient Ratio Test.

CLOGGING CRITERIA

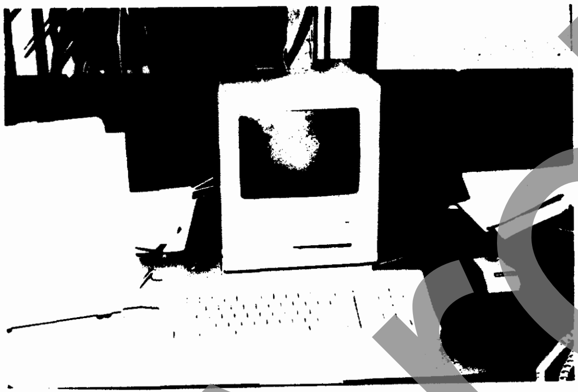
For critical / severe applications gradient ratio tests should always be conducted

For Critical/Severe applications, the gradient ratio test should always be conducted. Remember this test is a direct measurement of the clogging and retention potential for a geotextile. The suggested performance is the gradient ratio be less than or equal to 3.

STRENGTH REQUIREMENTS

	Class A	Class B
Grab Strength	180#	80#
Elongation	---	---
Seam Strength	160#	70#
Puncture Strength	80#	25#
Burst Strength	290#	130#
Trapezoidal Tear	50#	25#

Strength requirements for geotextiles used in the separation application for permeable bases.



Computer programs are available to help with the design of geotextiles.

D
A
M
P

The computer program DAMP provides an excellent module on the design of geotextile for Drainage.

Drainage Application

Lets talk about geotextiles used for drainage application. Wrapping an edgedrain trench is an example of a drainage application fro geotextiles.

AASHTO-AGC-ARTBA
Task Force 25

Guide Specifications and Test Procedures for Geotextiles

The AASHTO-AGC-ARTBA Task Force No. 25 provides guidance for drainage applications of geotextiles.

AASHTO-AGC-ARTBA Joint Committee
Subcommittee On
New Highway Materials
Task Force 25 Report

Guide Specifications and Test Procedures for Geotextiles

The materials information is published in the Guide Specifications and Test Procedures for Geotextiles.

STRENGTH REQUIREMENTS

	Class A	Class B
Grab Strength	180#	80#
Elongation	---	---
Seam Strength	160#	70#
Puncture Strength	80#	25#
Burst Strength	290#	130#
Trapezoidal Tear	50#	25#

When used in a drainage application, the geotextile should meet the strength requirements shown on the slide.

APPARENT OPENING SIZE

- Soil < 50% passing #200 Sieve
  AOS < 0.6 mm (AOS > #30 Sieve)
- Soil > 50% passing #200 Sieve
  AOS < 0.3 mm (AOS > #50 Sieve)

Soil Retention

If the soil has 50 percent retained on the No. 200 sieve, then the AOS should be greater than the No. 30 sieve.

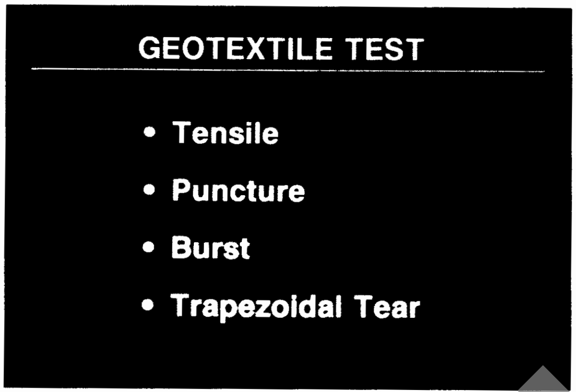
If the soil has greater than 50 percent passing the No. 50 sieve, then the AOS should be greater than the No. 50 sieve.

PERMEABILITY

$$k_{(geotextile)} \geq k_{(soil)}$$

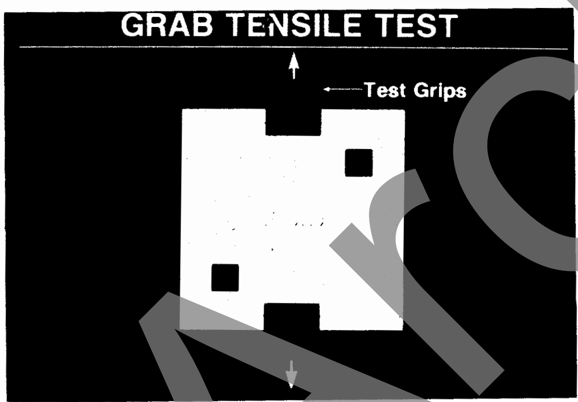
The permeability of the geotextile should be greater than or at least equal to the permeability of the soil.

Geotextile Tests



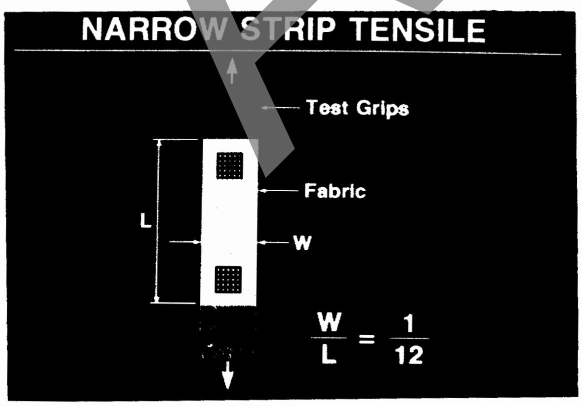
This is a list of existing geotextile tests that we use to model strengths necessary to survive the construction phase of the separator layer and the permeable base. It is important to realize that these tests were not developed for construction applications and therefore should be used with engineering judgement.

- Tensile
- Puncture
- Burst
- Trapezoidal Tear

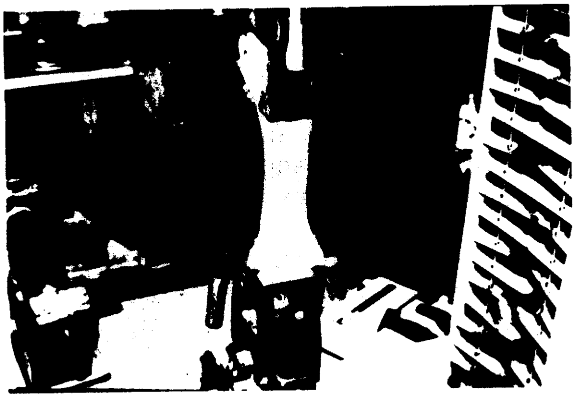


The grab tensile test models the stress placed on the geotextile during the compaction of the permeable base. During compaction two separate aggregate particles will want to spread out. When they contact the geotextile they will place the geotextile in tension.

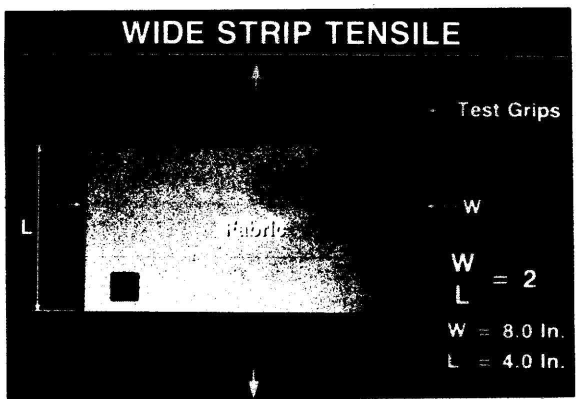
The specimen is 4" wide by 6" long. The jaws a 1" and centered on the specimen. Test method ASTM D 4632.



The narrow strip tensile test

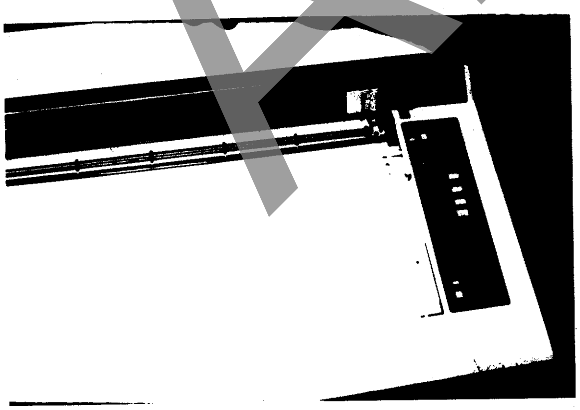


The narrow strip test is not used much because it gives high strength values because of the "roping" effect of the narrow strip of the geotextile.



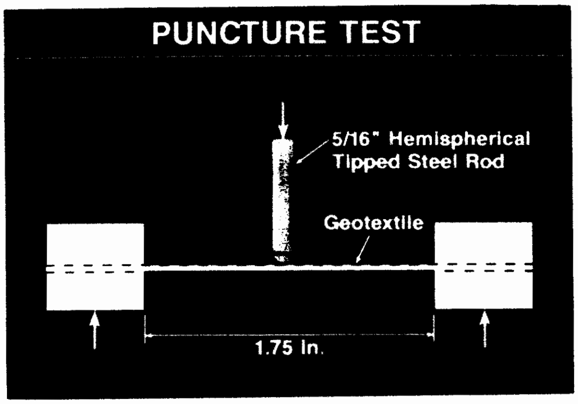
The wide strip tensile test is used quite a bit for performance. The specimen is 8" wide and 4" long. The test is performed in accordance with ASTM D 4595. Because of the wide strip, necking of the geotextile does not occur.

Test under operation



Recording device for the test apparatus.

Failure is determined by stress-strain curve.



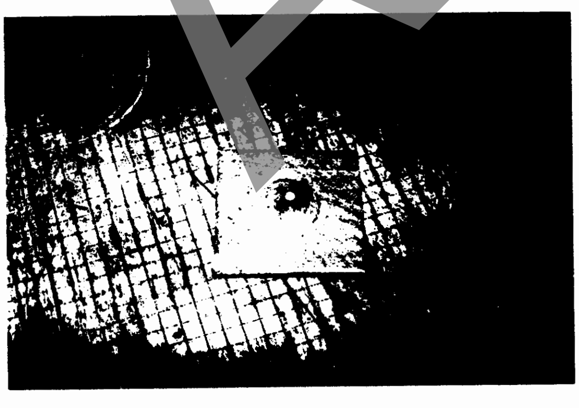
The puncture test is an index test for the geotextile's resistance to puncture. Application for this test could include the hauling truck driving over the aggregate spilled on the geotextile shown in a previous slide.

A geotextile sample is clamped in a ring that has an opening diameter of 1.75 inches. A 5/16" diameter rod is applied to the geotextile.

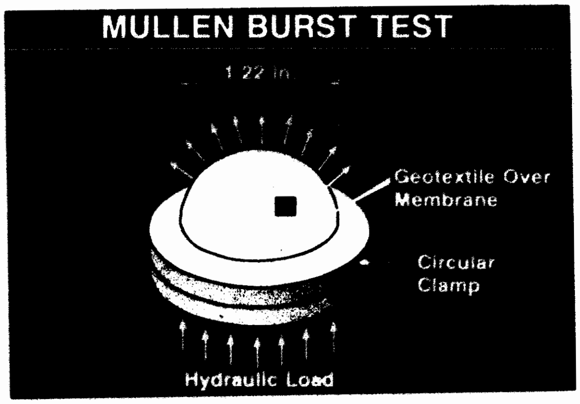
This test is conducted in accordance with ASTM D 3787.

The rod is hemispherical in shape at the tip.

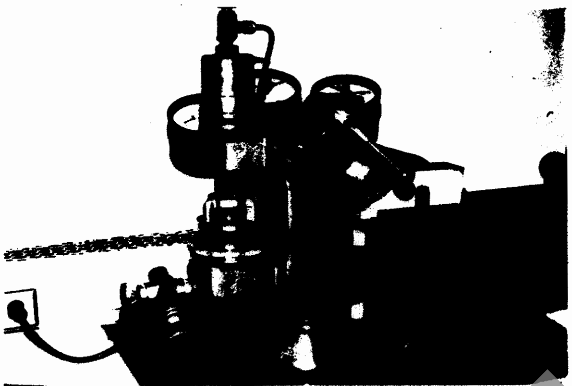
Test being performed.



Specimen after testing.



The Mullen Burst Test models the effect of the soil pressure on the geotextile as the soil is loaded. Because the permeable base has a high amount of voids, the soil pressure will try to push the geotextile into a void.
The geotextile is placed between the two clamps. A hydraulic pressure is applied to a rubber membrane which applies the load to the geotextile. This test is performed in accordance with ASTM D 3786.

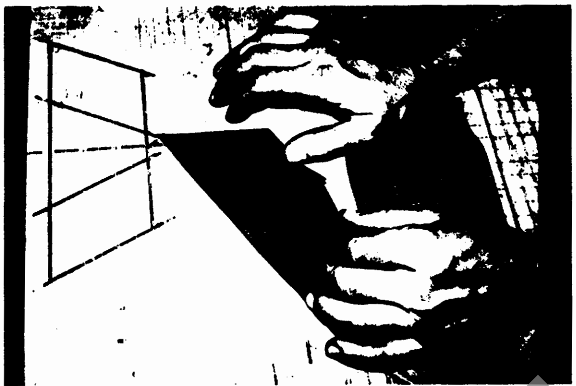


Test apparatus.

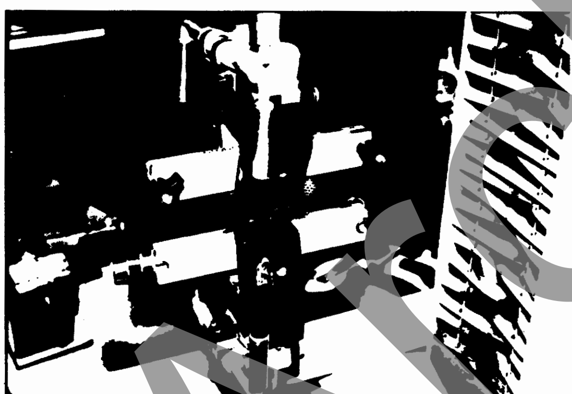
Bottom clamp and the rubber membrane.

Test being performed

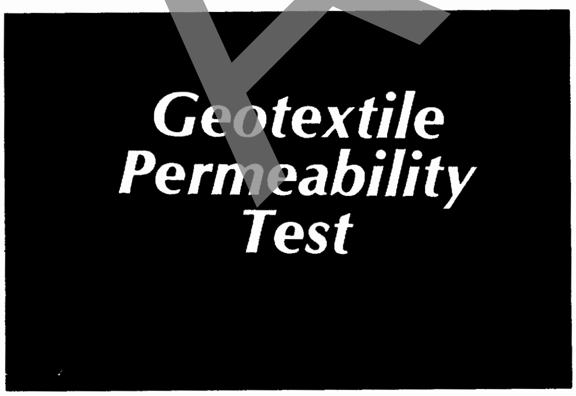
Trapezoidal Tear models the propagation of a tear in the geotextile during installation. This test is performed in accordance with ASTM D 4533.



The specimen is cut into a trapezoidal shape. This test attempts to load the individual filaments of the geotextile during the test.

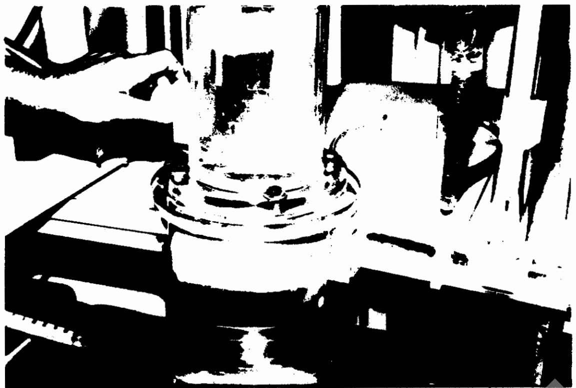


On the right a 5/8" long cut slice is made to the process. You can see that the end of the specimen is placed parallel to the load clamp causing a fold in the specimen. The load to tear the entire width of the geotextile is measured.



Finally we need to determine the geotextile's permeability.

The geotextile is placed between the cylinders.



The top half is clamped on.

The constant head test is used to determine the coefficient of permeability of the geotextile.

Separation Application

The geotextile can also be used in a separation application. Separating the permeable base and the subgrade is an example of a separation application.

For drainable pavement systems, the geotextile SHOULD BE DESIGNED FOR SEPARATION APPLICATION.

AASHTO-AGC-ARTBA Task Force 25

Guide Specifications and Test Procedures for Geotextiles

The AASHTO-AGC-ARTBA Task Force No. 25 also provides guidance for the separation function of geotextiles.

CONSTRUCTION SURVIVABILITY RATINGS

Soil CBR	< 1		1-2		> 2	
Equipment Ground Contact Pressure (psi)	> 50	< 50	> 50	< 50	> 50	< 50
Cover Thickness (in)						
4	NR	NR	H	M	M	M
6	NR	NR	H	H	M	M
12	NR	H	M	M	M	M
18	H	M	M	M	M	M

The construction survivability table. The geotextile should meet the minimum strength for the following tests. (read off slide). Two levels of survivability are provided. If the geotextile has less than 50% elongation, use the high level.

If the geotextile has greater than 50% elongation, use the low stress level.

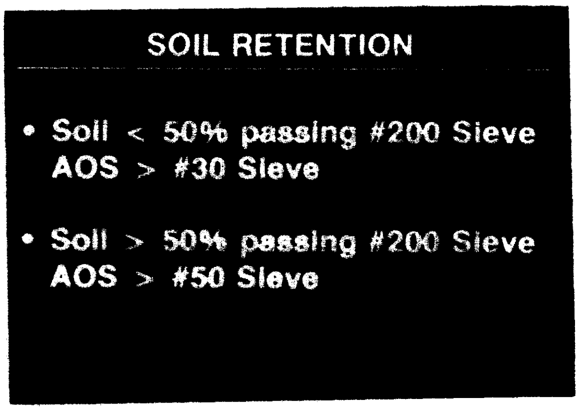
A high stress level is recommended for use as a separation layer.

PHYSICAL PROPERTY REQUIREMENTS

< 50% Geotextile Elongation /
> 50% Geotextile Elongation

Survivability Level	Grab Strength (Lbs)	Puncture Resistance (Lbs)	Trapezoid Tear Strength (Lbs)
High	270/180	100/75	100/75
Medium	180/115	70/40	70/40

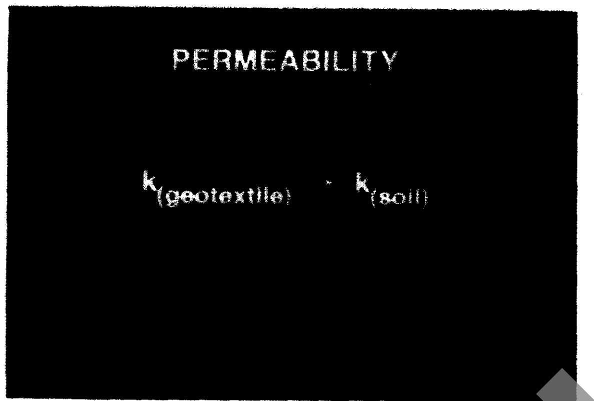
Physical Properties table



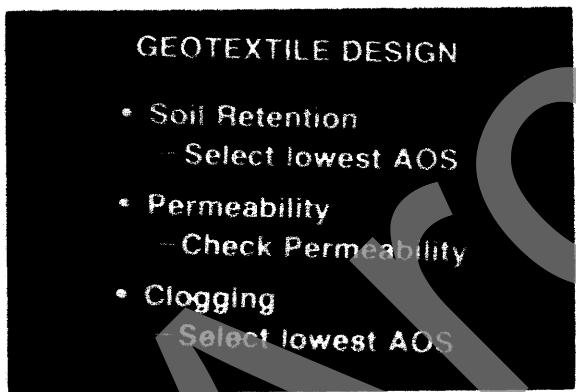
Soil Retention

If the soil has less than 50 percent passing the No. 200 sieve, then the AOS number should be greater than the No. 30 sieve.

If the soil has more than 50 percent passing the No. 50 sieve, then the AOS number should be greater than the No. 50 sieve.



The permeability of the geotextile should be greater than the permeability of the subgrade soil.



Summarizing the geotextile design for the separation application.

Select the lowest AOS for soil retention and clogging.

The permeability of the geotextile should exceed the permeability of the soil.

CONSTRUCTION CONSIDERATIONS

- Smooth, Strong Subgrade
- Highest Quality of Construction

Geotextiles should be placed and covered as quickly as possible. This will prevent damage due to overexposure to the sun and construction traffic.

Care should be used in placing the geotextile so that it won't have wrinkles, tears, or rips.

The subgrade should be strong and smooth. Usually the permeable base is placed over the geotextile. Therefore the subgrade must provide support to the slab.

High quality construction is required to prevent damage to the geotextile during its placement and placement of the permeable base.

Edgedrains

Edgedrains

Edgedrains are a key element in a pavement drainage system. They remove the water from the permeable base.

TYPES OF EDGEDRAINS

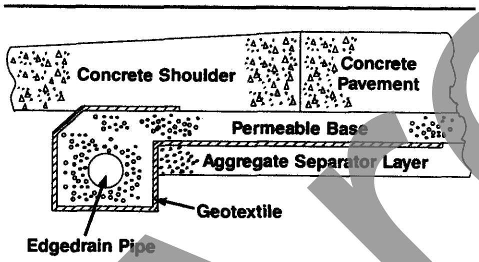
- Aggregate Trench
- Conventional Pipe
- Geocomposite Fin Drains

There are three basic types of edgedrains:

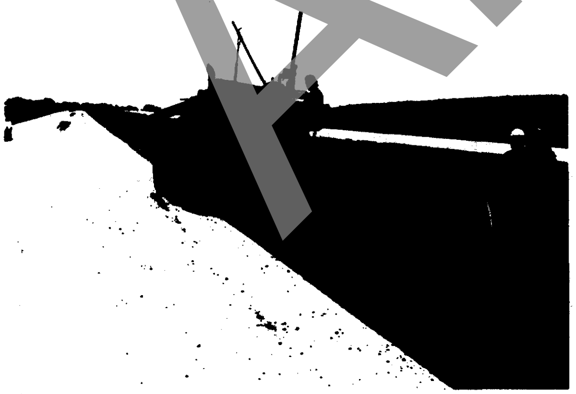
1. Aggregate Trench.
2. Pipe Edgedrain.
3. Geocomposite Fin Drain.

Aggregate trenches are not recommended because of their low hydraulic capacity. Geocomposite fin drains are not recommended because of their inability to be cleaned.

GEOTEXTILE PLACEMENT AROUND EDGEDRAIN

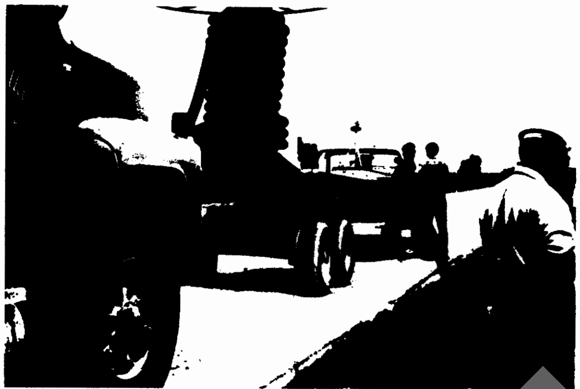


Geotextile placement will vary depending on whether the edgedrain is installed before or after the construction of the permeable base. The trench should be lined with a geotextile, but the top of the trench, adjacent to the permeable base, is left open to allow a direct path for the water to enter the pipe. The primary purpose of the geotextile is to keep fines from entering the trench. The permeability of the geotextile should exceed the permeability of the subgrade.



Trenching equipment is used to dig out the trench.

For the post-pave application, the geotextile lines the trench. The geotextile is stopped at the bottom of the permeable base. The geotextile would overlap the subgrade or separator layer if the permeable base has not been placed.



The edgedrain is placed in the trench.

The contractor has placed subgrade material on the geotextile to keep it from flopping over. This is not a recommended practice as the subgrade soil could contaminate the trench. Notice the overlap of geotextile adjacent to the concrete pavement. We want to ensure that the geotextile DOES NOT block the drainage path through the permeable base.

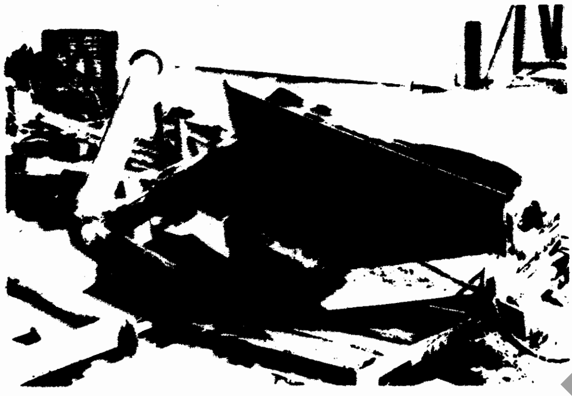
Also notice the dips or bends in the edgedrain. Where are the outlet pipes?

Placing the open graded base course as trench backfill. Now one can see the geotextile blocking the drainage path in the permeable base. The water will have to travel through the geotextile to get to the edgedrain.

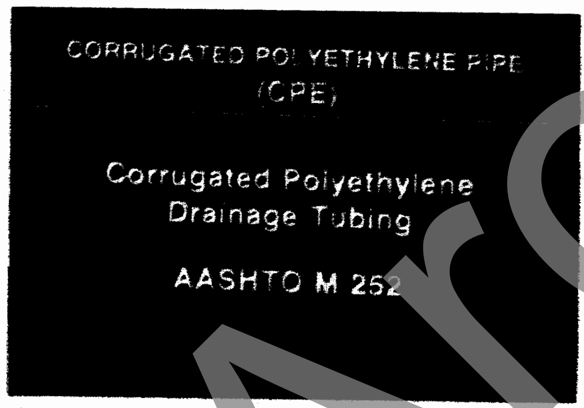
There should be unrestricted flow through the permeable base to the edgedrain.

Post-pave rehabilitation installation of edgedrain pipe. The purpose of this application is to remove water entering the pavement lane shoulder joint.

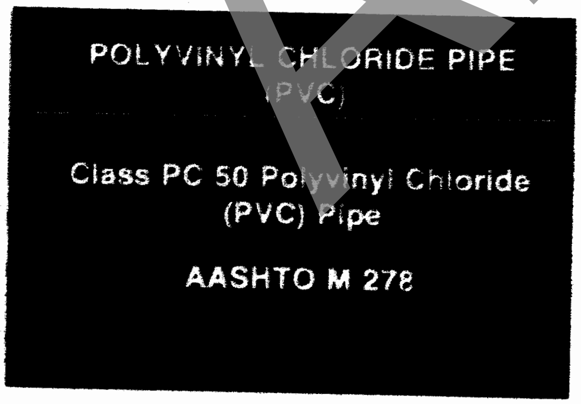
This device aligns and places the edgedrain pipe and places the backfill material.



The device is taken apart to show how the edgedrain is placed and aligned then the placement of the backfill material.



When corrugated Polyethylene Pipe (CPE) as the edgedrain, the pipe should meet the material requirements in AASHTO Specification M 252.



For polyvinyl chloride pipe (PVC) the pipe should meet AASHTO Specification M 278, Class PC 50.

CORRUGATED-SMOOTH PIPE

- ASTM F 949
- PVC Corrugated Sewer Pipe with a Smooth Interior

Corrugated polyvinyl chloride pipe with a smooth interior should meet requirements in ASTM F 949.

ASPM TRENCH BACKFILL

- Edgedrain pipe should be capable of resisting ASPM

If the pipe is to be installed in trenches and the trenches will be backfilled with asphalt stabilized permeable material, the edgedrain should be capable of resisting the temperature of the asphalt stabilized permeable material.

HEAT RESISTANT PIPE

- PVC 90° electric plastic conduit
- EPC-40 or EPC-80
- NEMA Specification TC-2

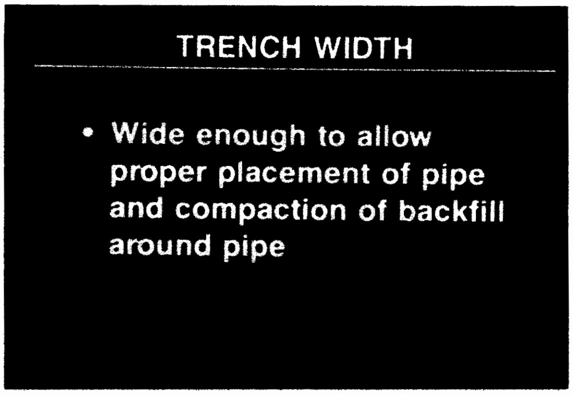
For heat resistant pipe, PVC 90° electric plastic conduit, either EPC-40 or EPC-80 conforming to the National Electrical Manufacturers Association Specification TC-2.

TRENCH BACKFILL

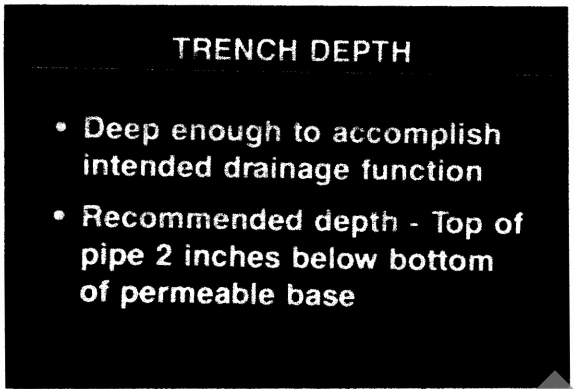
- Pre-pave installation, trench backfill should be the same material as the permeable base
- Post-pave installation, trench backfill should be as permeable as the permeable base

Trench backfill should be the same material as the permeable base for the pre-pave installation.

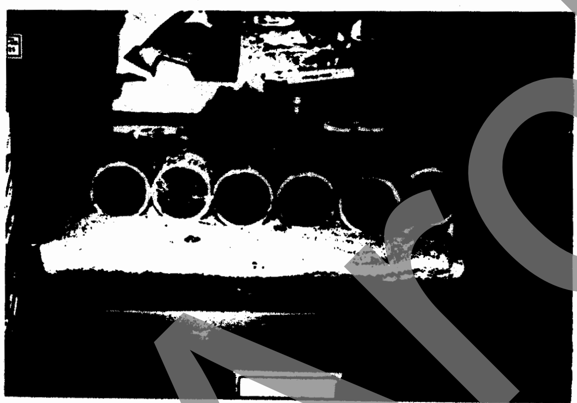
In the post-pave installation, the trench backfill should have or exceed the permeability of the permeable base.



The trench width should be wide enough to allow proper placement of the pipe and compaction of the backfill. Usually a trench width of 8 to 10 inches is used.



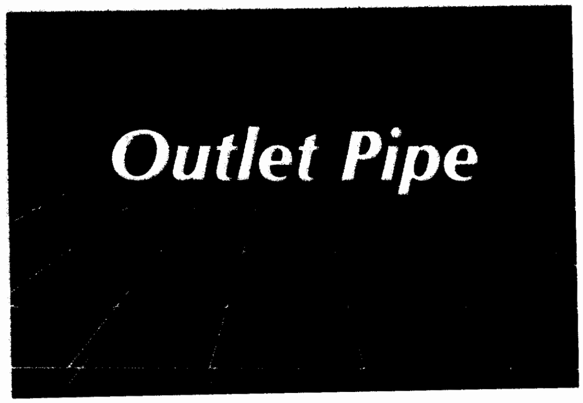
The trench depth should be deep enough to serve its intended drainage function. It is recommended that the trench be deep enough for the top of the edgedrain pipe to be located 2 inches below the bottom of the permeable base.



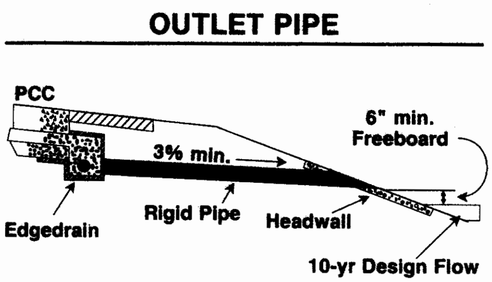
Plugged edgedrains.

Wrapping the edgedrain trench with a geotextile is necessary to keep fines from entering the edgedrain trench and plugging the pipe.

Plugged edgedrains. The drainable pavement system is as good as its weakest link. Is this pavement drainage system going to provide adequate drainage?

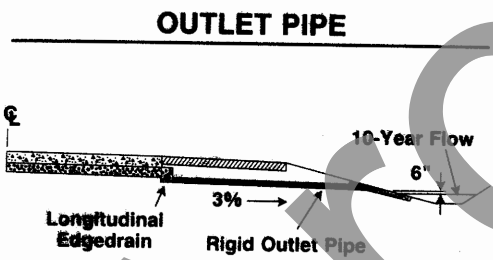


Outlet Pipes



Outlet pipes are critical to the drainage system. The outlet pipe system consists of a rigid PVC pipe connected to the edgedrain and a headwall at the embankment slope.

A minimum slope of 3 percent is recommended to provide drainage.



The invert of the outlet pipe should be at least 6 inches above the 10 year design flow in the ditch. Some states provide invert elevations for outlet pipes on plans to ensure coordination of surface drainage.

RIGID PIPE

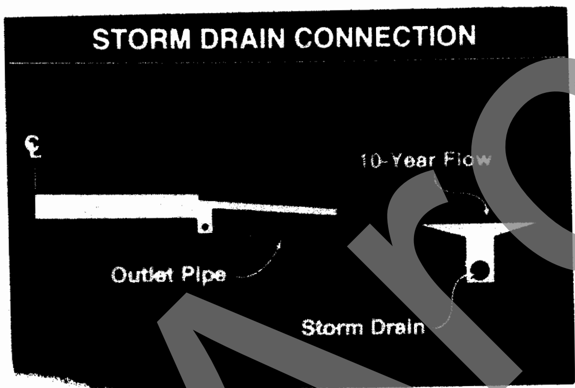
- ASTM D 3034 - 89
- PVC Sewer Pipe
- SDR 23.5

Outlet pipe should be rigid polyvinyl chloride sewer pipes conforming to ASTM D 3034-89.

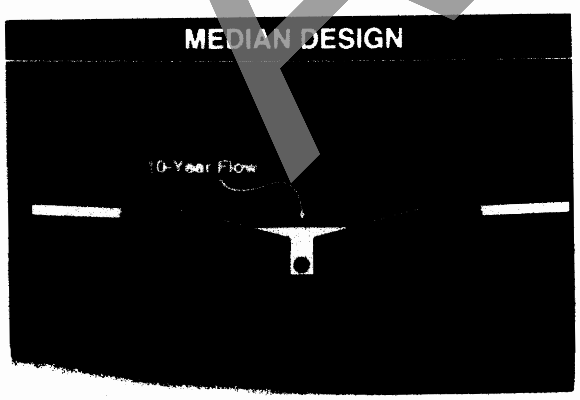
This is an in-place outlet pipe. Do you think this outlet pipe is providing drainage of the permeable base. If we can't outlet the water, the permeable base will act as a sponge and can accelerate pavement deterioration.

This is another reason for using rigid pipe at the outlets.

Water ponding at the headwall of an outlet pipe. We must remember to grade the soil around the outlet pipe to provide positive drainage from the drainable pavement system.



If ditches or medians are too flat to outlet the edgedrain system, a storm drain system may have to be installed to collect the water. Edgedrain outlets can be tied into the storm drain catch basins.



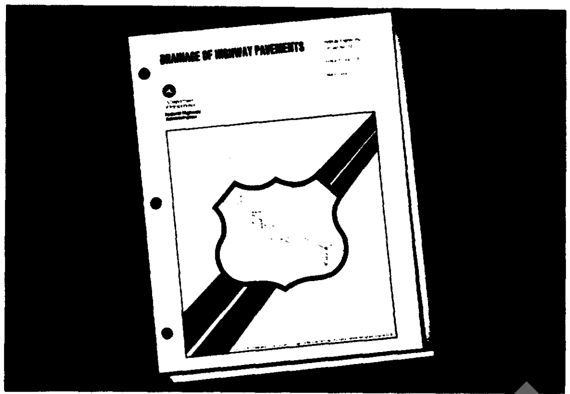
A storm drain system should be provided to reduce the amount of water in the median. This will reduce the chance of water infiltrating the pavement section from the median ditch.

SURFACE WATER COORDINATION

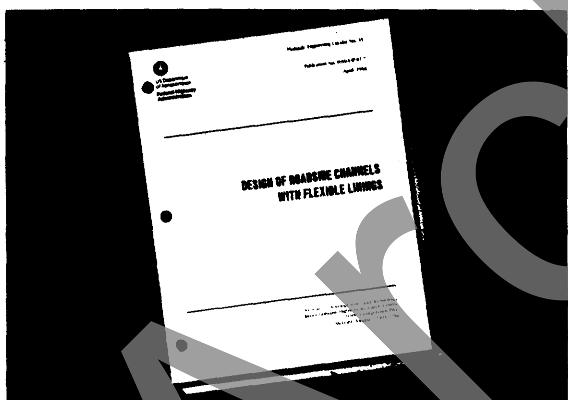
Subsurface and surface water must be coordinated

It is imperative that surface drainage and the permeable base drainage system be coordinated with each other.

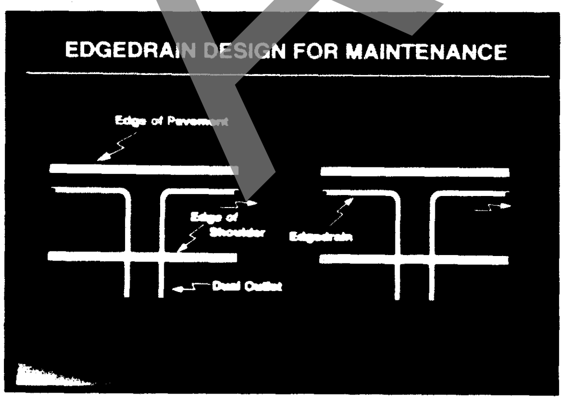
If surface water backs up the pipe the pavement section will be saturated until the surface water elevation recedes permitting the permeable base to drain.



HEC Drainage of Highway Pavements provides guidance for the design of water flowing on pavement surfaces.

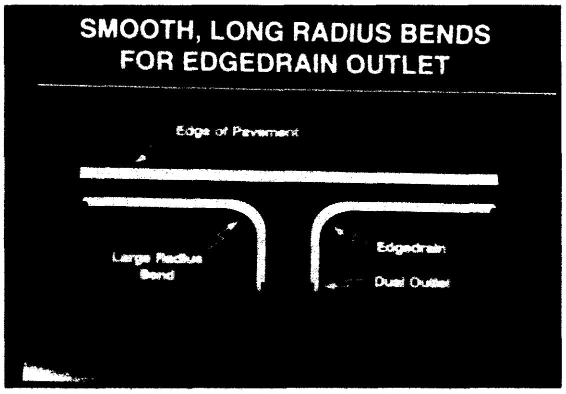


HEC No. 15, Design of Roadside Channels with Flexible Linings provides guidance for the design of roadside ditches.



The edgedrain and outlet system should be designed with maintenance in mind. Usually we will want to flush or jet rod the system. This system has outlet pipes at both ends of the edgedrain pipe. This will allow the edgedrain to be flushed.

If part of the edgedrain becomes clogged over time, only the pavement section between the outlet pipes will be effected.



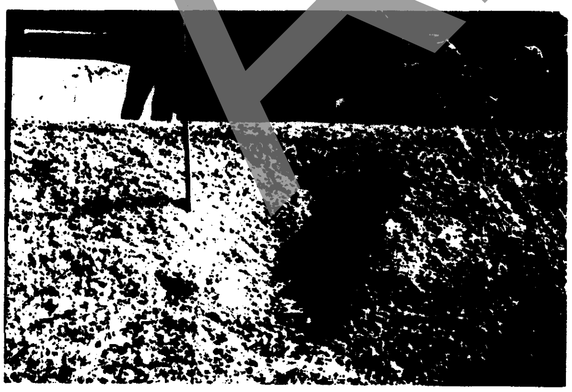
Smooth, long radius bends in the edgedrain system should be provided so rodding equipment can navigate the bends. Radii of 2 to 3 feet should be acceptable for jet rodding or cleaning equipment.

OUTLET SPACING

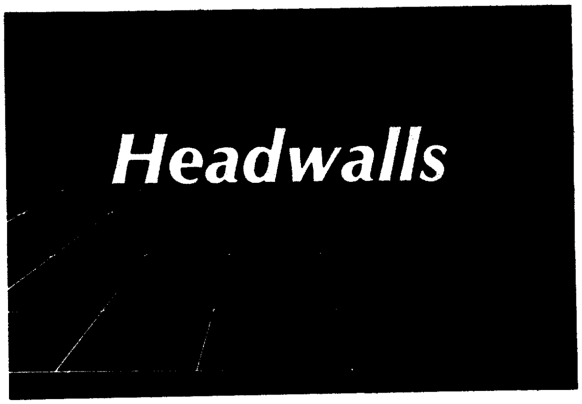
- Limited to 250 feet
- Segmented Sections

A maximum outlet spacing of 250 feet is recommended. It is also recommended that edgedrains be segmented between outlets so that each section drains separately.

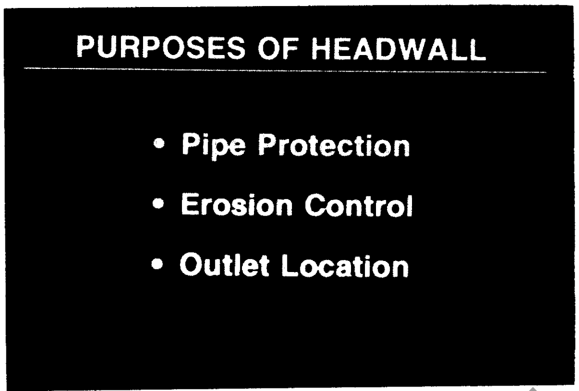
We not only have to coordinate pavement infiltration drainage with surface drainage, but must coordinate with other highway features. Here is a slide of a guardrail post that has been driven directly on top of the outlet pipe.



Here is another installation of guardrail post that has been driven on top of the outlet pipe. Remember, that in most cases, when guardrail is installed it is usually 2 feet off the edge of the shoulder and you must be careful that posts are not driven through the edgedrain or outlet pipes.

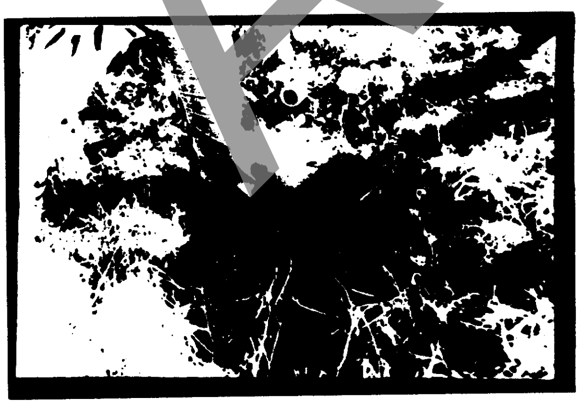


Headwalls



Headwalls protect the outlet pipe from damage due to mowing, prevent slope erosion, and aid in the location of outlet pipe for future maintenance operations.

Without headwalls, errant trucks or mowing operations can damage the end of the outlet pipes clogging the drainage system.



Pipe erosion

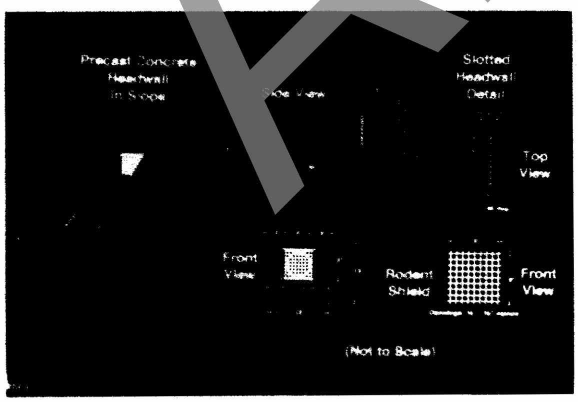
Pipe erosion

Pipe erosion

RODENT SCREENS

FHWA recommends the use of rodent screens

Rodent screen are recommended because rodents can build nests in pipe edgedrains. Screens should be able to be remove so that they can be cleaned. Sometimes erodible fines will build up on rodent screens.



A design of a pre-cast headwall

Pre-cast headwall

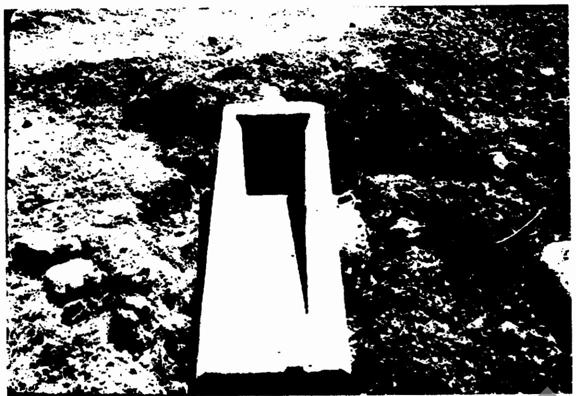


Photo of a pre-cast headwall.

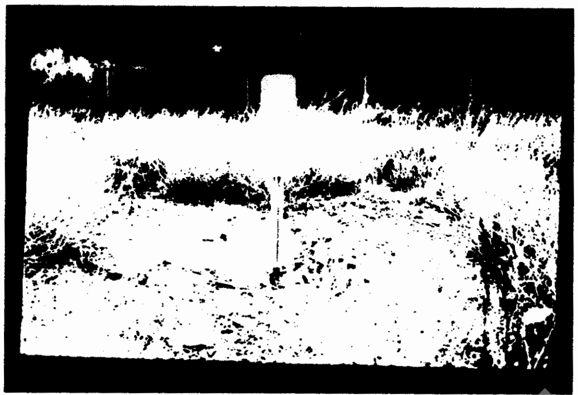
Oklahoma fabric foam

Oklahoma fabric foam

REFERENCE MARKERS

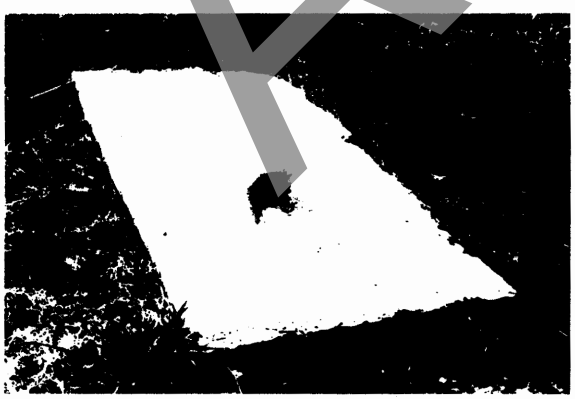
FHWA recommends the use of reference markers

Reference markers are recommended to help locate the outlet pipe for future inspection of maintenance.



States have used flexible delineator post

Others have simply painted a mark on the shoulder.



Headwalls can be cast in-place.

CONSTRUCTION CONSIDERATIONS

- Place pipe to line and grade
- Provide proper compaction of trench backfill
- Provide headwalls

Outlet pipes should be placed to line and grade. Some States even put invert elevation on outlet pipes to ensure proper fall on the outlet pipe.

Proper compaction is critical to provide support for the shoulder to minimize deterioration.

Headwalls should be provided to protect the end of the outlet pipe from mowing operations and errant trucks.

Construction operations can often damage the edgedrain system. This is a video tape shot of a crushed pipe.

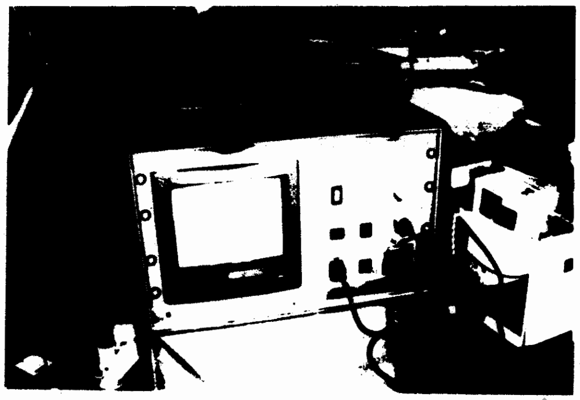
VIDEOTAPING

Videotape completed project for quality assurance

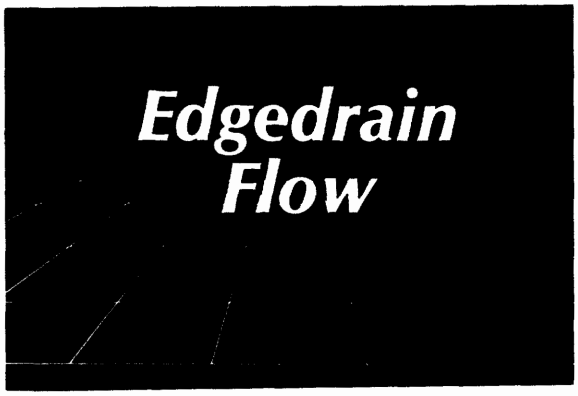
Videotaping the completed edgedrain system with fiber optic equipment is recommended for final acceptance of the project. This can detect construction failures while they can be corrected by the contractor. This will help minimize future headaches that maintenance forces will have to deal with later.

Camera tip that is pushed through the outlet and edgedrain pipes.

Video inspection equipment



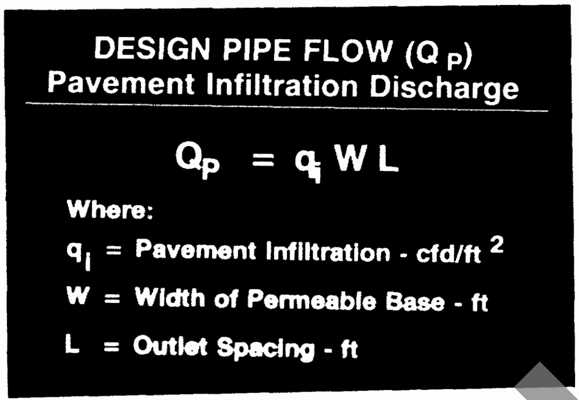
Video screen.



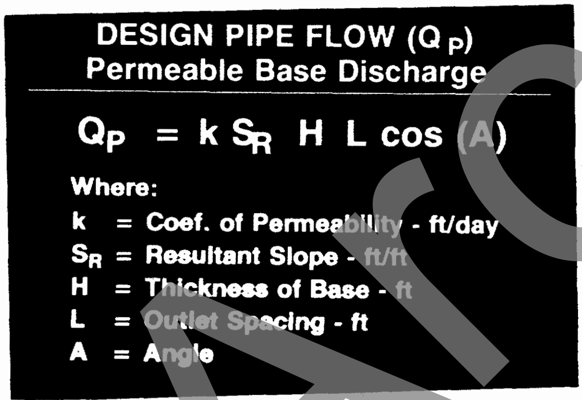
Edgedrain Flow

The capacity of the edgedrain and outlet spacing take on an added importance when permeable bases are provided. The capacity of the edgedrain system should always increase as the water flows in the system. Edgedrain design flow rate can be determined by

- Pavement Infiltration
- Permeable Base Discharge Rate
- Time to Drain Discharge Rate



For pavement infiltration, the design flow rate for the pipe Q_P is set equal to the pavement infiltration times the width of the base times the outlet spacing.



Another approach is to set the design flow rate equal to peak flow the permeable base can discharge to the edgedrain. The design flow rate is equal to the permeable base discharge rate which is coefficient of permeability of the base times the base thickness times the resultant slope of the base times the outlet spacing times the cosin of the angle between a line perpendicular to the roadway centerline and the resultant flow path.

DESIGN PIPE FLOW (Q_P)
Time to Drain Discharge

$$Q_P = (W\,L\,H\,N_e\,U)\left(\frac{1}{t_D}\right) \times 24$$

Where:
W = Width of Permeable Base - ft
L = Outlet Spacing - ft
H = Permeable Base Thickness - ft
U = Percent Drained - decimal
t_D = Drainage Time Period - hours

A third approach is to set edgedrain design flow rate to the time to drain discharge rate. The flow rate is determined by the formula.

$Q_p = (W\ L\ H\ N_e\ U)\ (1/t_D) * 24$
W is the width of the permeable base.
L is the outlet spacing
H is the thickness of the base.
N_e is the effective porosity of the base.
U is percent drained.
t_D is the drainage time in hours.

The first term, in parentheses, is the amount of water drained during the design time period. The second term converts the flow to an hourly rate. The third term converts it to a daily rate.

MANNING'S EQUATION

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}$$

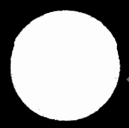
Where:
Q = Flow - cfs
A = Flow Area - ft^2
R = Hydraulic Radius ($\frac{A}{P}$) - ft
S = Slope - ft/ft
n = Roughness Coefficient

Once the edgedrain pipe design flow rate is determined, Manning's equation can be used to size the pipe.

$$Q=\frac{1.486}{n}AR^{2/3}S^{1/2}$$

Q is Pipe flow, cfs.
A is Flow area within the pipe, sf.
R is the Hydraulic radius.
S is the slope of the pipe, ft/ft.
n is Manning's roughness coefficient.

HYDRAULIC RADIUS (R)



$$R = \frac{A}{P}$$

Where:
A = Flow Area - ft^2
P = Wetted Perimeter - ft

The hydraulic radius is the flow area in the pipe divided by the wetted perimeter in the pipe.

MANNING COEFFICIENT (n)

Smooth	0.012
Corrugated	0.024

Manning's roughness coefficient for smooth pipes is 0.012. For corrugated pipes it is 0.024.

Smooth pipes of the same diameter as corrugated pipes will have 2 times the discharge. Knowing that V=Q/A, the velocity is also twice as great helping move sediment through the pipe.

MANNING'S EQUATION
Circular Pipe - Flowing Full

$$Q = \frac{.4631}{n} D^{8/3} S^{1/2}$$

Where:

Q = Flow - cfs

D = Diameter - ft

S = Slope - ft/ft

n = Roughness Coefficient

For a pipe flowing full, Manning's equation can be simplified to:

$$Q = \frac{.4631}{n} D^{8/3} S^{1/2}$$

This equation gives flow in cfs.

MANNING EQUATION
Circular Pipe - Flowing Full

$$Q = \frac{53.01}{n} D^{8/3} S^{1/2}$$

Where:

Q = Flow - cf/day

D = Diameter - inches

S = Slope - ft/ft

n = Roughness Coefficient

Converting the equation so that Q will be in cf/day, Manning's equation for full flow will be

$$Q = \frac{53.01}{n} D^{8/3} S^{1/2}$$

PIPE CONVEYANCE

$Q = K\,S^{1/2}$

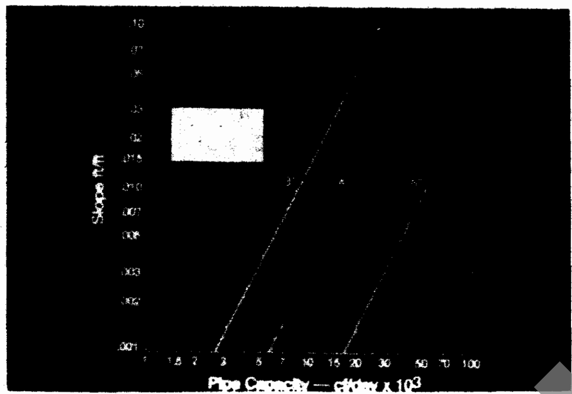
K = Pipe Conveyance

If the diameter of the pipe and the roughness coefficient are assigned, then Manning's equation can be simplified to
$Q = K\,S^{½}$. K is pipe conveyance in cubic feet per day.

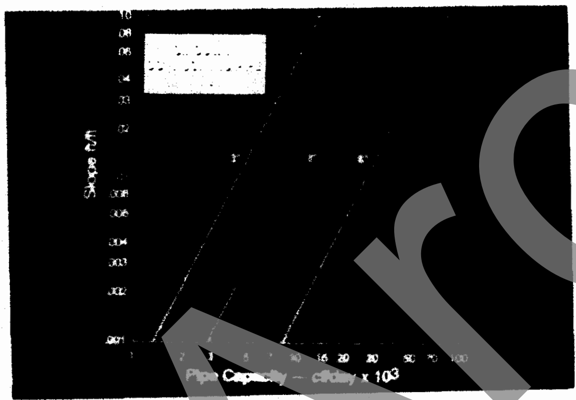
CONVEYANCE TABLE

Pipe Size	Smooth Pipe (n = 0.012)	Corrugated Pipe (n = 0.024)
3"	82,699	41,349
4"	178,102	89,051
6"	525,105	262,553

A conveyance table is provided for different size corrugated and smooth pipes. The pipe conveyance is read from pipe size and type and is multiplied by the square root of the pipe slope to give pipe capacity.



Design charts for capacity are provided with the different sizes of pipes. The pipe capacity of the smooth pipe is determine by moving horizontally, from the pipe slope, until intersecting the pipe size. The pipe capacity is read vertically from the intersection point.



A similar chart is provided for corrugated pipes.

MANNING'S EQUATION FOR VELOCITY

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where:

V = Velocity - ft/sec

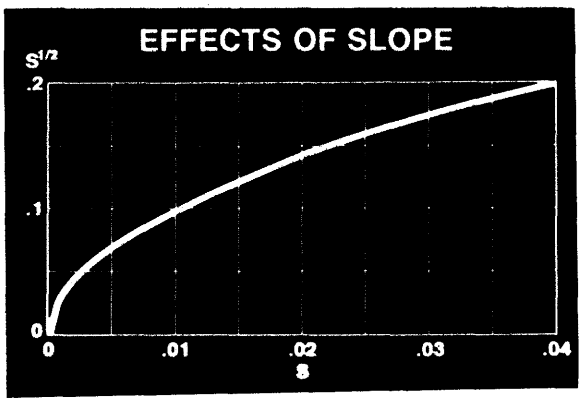
R = Hydraulic Radius - ft

S = Slope - ft/ft

n = Roughness Coefficient

The velocity of the water in the pipe can be calculated by dividing Manning's equation by the flow area.

For cleaning action, the velocity of flow in the pipe should be greater than or equal to 2 feet per second.



This chart illustrates the effect of slope as an input to Manning's equation.

MINIMUM PIPE SLOPE

- Theoretical Criteria - 2 ft / sec flowing full

• Manning's n	Pipe Slope - 4" Dia
n = 0.012	.00717 ft/ft
n = 0.024	.0287 ft/ft

In theory the minimum pipe slope should be set to provide a flowing full velocity of 2 feet per second for cleaning purposes. For a 4" diameter pipe smooth pipe, the minimum slope would have to be 0.717%. For a corrugated 4" diameter pipe, the slope would have to be 2.87%.

MINIMUM VELOCITY - ft/sec

	Smooth Pipe (n = 0.012)	Corrugated Pipe (n = 0.024)
3"	2.17	1.08
4"	1.65	.83
6"	1.36	.68

S = 0.01 ft/ft
Depth Ratio = 0.25

This table shows velocities of different types and sizes of pipes for a pipe at a slope of 0.01 ft/ft flowing 1/4 full.

MINIMUM PIPE SLOPE

- Not practical
- Pipe slope same as roadway
- Rigorous maintenance

Setting a minimum pipe slope is not practical. Most SHA's show edgedrain pipes in a standard drawing. The top of the edgedrain pipe is located off of the pavement surface. Therefore, the pipe slope is set to that of the roadway profile. Rigorous maintenance of these pipes will be required.

OUTLET SPACING (L)
Pavement Infiltration Discharge

$$L = \frac{K\,S^{1/2}}{q_i\,W}$$

Where:

K = Conveyance of Pipe
S = Pipe Slope - ft/ft
q_i = Pavement Infiltration - cfd/ft ^{2}
W = Width of Permeable Base - ft

Outlet spacing can be determined by:

- Pavement infiltration
- Permeable base discharge
- Time to drain discharge

For pavement infiltration the outlet spacing is determined by:

$$L=\frac{KS^{1/2}}{q_iW}$$

K is pipe conveyance.
S is pipe slope.
q_i is pavement infiltration.
W is the width of the permeable base.

OUTLET SPACING (L)
Permeable Base Discharge

$$L = \frac{K\,S^{1/2}}{k\,S_R\,H\cos A}$$

Outlet spacing for permeable base discharge is determined by:

$$L=\frac{KS^{1/2}}{kS_RH\cos A}$$

K is pipe conveyance.
S is pipe slope.
k is base coefficient of permeability.
S_R is the resultant slope.
H is base thickness.
A is the angle between a line perpendicular to the roadway and the resultant slope.

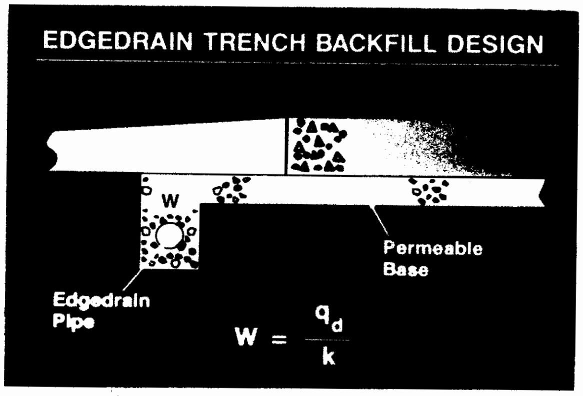
OUTLET SPACING (L)
Time to Drain Discharge

$$L = \frac{K\,S^{1/2}\,t_D}{24\,(W\,H\,N_e\,U)}$$

Outlet spacing for the Time to Drain discharge can be determined by:

$$L=\frac{KS^{1/2}t_D}{24WHN_eU}$$

K is pipe conveyance.
S is pipe slope.
t_D is the drainage time.
W is the width of the base.
H is base thickness.
N_e is base effective porosity.
U is the percent drained.



The edgedrain trench should transmit the discharging water to the edgedrain pipe. The width can be determined by dividing the base discharge by the coefficient of permeability of the trench backfill material.

PIPE OPENINGS

- Slotted
  - $D_{85} > 1.2$ Slot Width
- Circular
  - $D_{85} > 1.0$ Hole Diameter

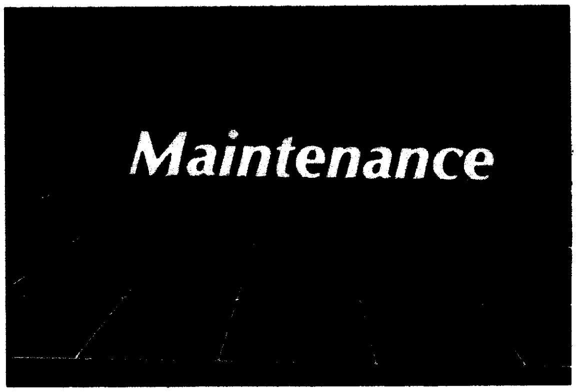
For slotted pipes, the D_{85} of the trench backfill is determined. The slot width should be less than 1.2 times the D_{85} of the trench backfill.

For circular holes, the hole diameter should be less than the D_{85} of the trench backfill.

OUTLET SPACING

250 feet

The recommended maximum outlet spacing should be 250 feet.



Maintenance

Maintenance is critical to the continued success of any longitudinal edgedrain system. If a State is not willing to make a maintenance commitment, pavement drainage systems should not be used since the drainage system will eventually become clogged, saturating the pavement section which will increase the rate of deterioration.

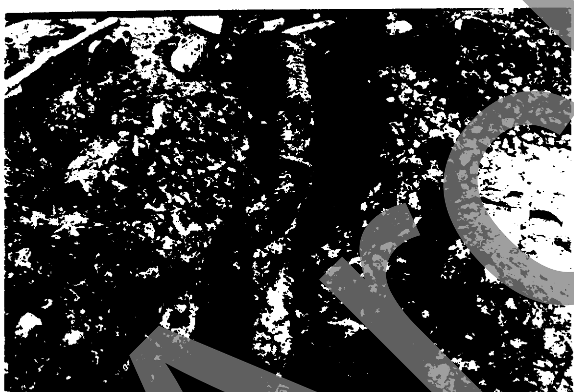
When the outlets are clogged, the permeable base does not serve its intended function. You can see the initial stage of pumping of this project. If the outlets are clogged, the water will find some way to exit the pavement drainage system. Staining is the indication of pumping. This is the first stage of loss of support for the pavement slab.

Outlets may be clogged by being crushed.

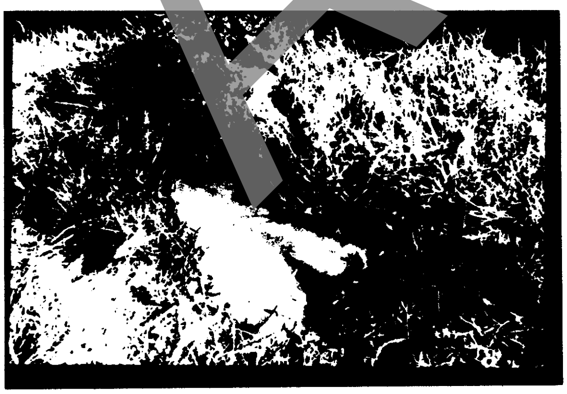
Rodent screens have to be periodically removed and cleaned. Often the screen sill retain sediment and debris which will clog the outlet.

Outlets must regularly inspected to ensure that sediment does not clog the outlet pipe.

Vegetation is another common cause of outlet clogging. See the increase of cattails at the location of the outlet pipe.

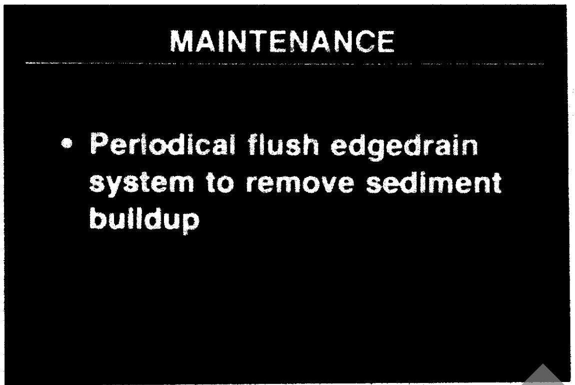


Construction damage can render a pavement drainage system segment useless. This pipe was crushed by construction equipment

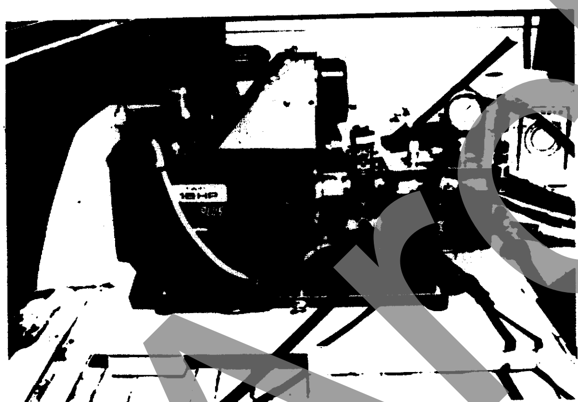


Another item of inspection should be sediment build-up downstream of the pipe. Sediment build-up downstream can cause water ponding and keep water in the edgedrain system and base.

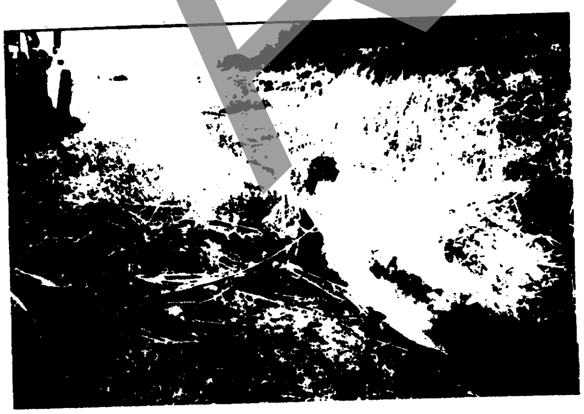
Plugged outlet



The edgedrain system should be periodically flushed to remove any sediment buildup within the system. This is the reason for providing an upstream and downstream outlet for each edgedrain segment.

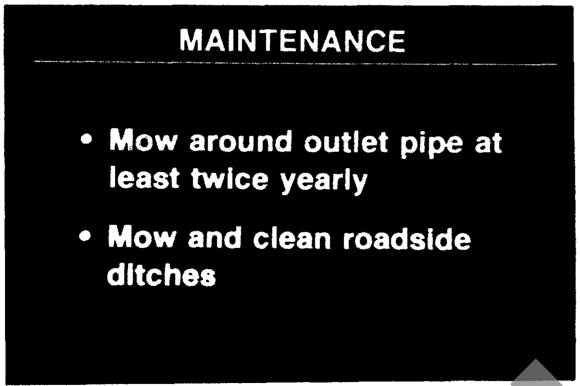


Portable pumps can be used to clean edgedrain and outlet pipes.

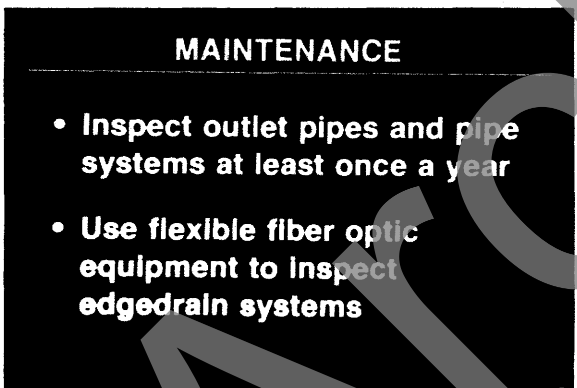


Picture of jetting tip.

Cleaning of pipes.

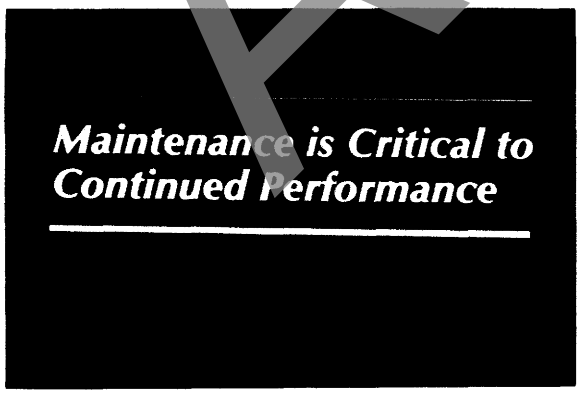


We recommend that roadside should be mowed at least twice yearly. This not only includes around the outlet pipe, but everything along the roadside drainage path.

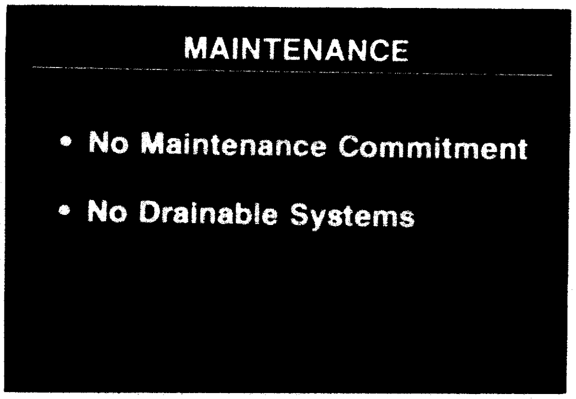


As a minimum requirement, maintenance inspections for pavement drainage should be performed at least once a year. As a minimum, the outlet pipes should be inspected once a year.

We recommend that flexible fiber optic be used to inspect the entire edgedrain system.



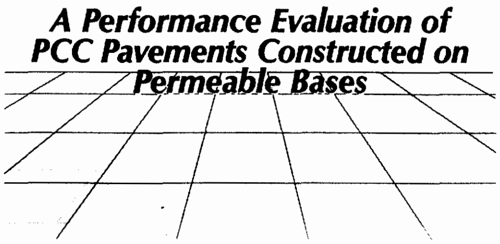
Maintenance is critical to the long-term performance of the drainage system and the pavement structure.



If there will not be a commitment to the maintenance of the drainage system, Pavement Drainage Systems should not be provided.

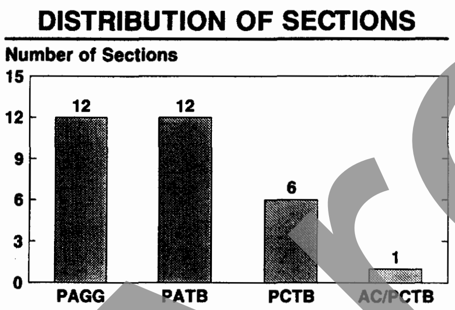
If the drainage system does not properly function, it can actually increase the rate of pavement deterioration.

Rodent screens are necessary. Here is our friend the groundhog after Bill Murray chased him off of the golf course.



A performance evaluation of
pcc pavements constructed on
permeable bases was performed by ERES
Consultants

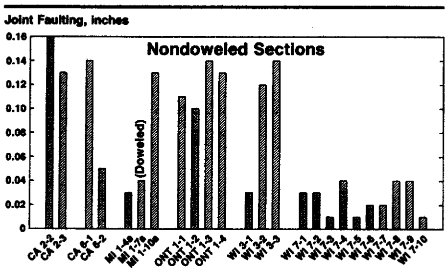
31 sites were evaluated in 7 different states. These states included California, Maryland, Michigan, Minnesota, Missouri, Missouri, and Wisconsin.



This evaluation included sites with different design types and different permeable bases. This slide shows the distribution of sections for each type of permeable base.

PAGC = unstabilized permeable base
PATB = asphalt stabilized permeable base
PCTB = cement stabilized permeable base
AC/PCTB = Hot mix asphalt over cement stabilized permeable base

AVERAGE FAULTING



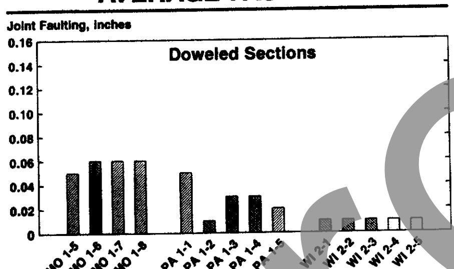
Some of the projects were placed as experimental projects evaluating the effect of different design features. Thus, the performance of the pavement constructed on permeable bases can be compared to adjacent sections with dense graded aggregate bases.

This chart represents the effect of permeable bases on Jointed Concrete Pavements (plain & reinforced) without load transfer devices. The yellow bars represent those sections built on permeable bases where the red represents those sections built on non-permeable dense graded base sections.

In most cases the performance of the permeable base sections is better than the dense graded aggregate base sections. The Wisconsin 7 project was completed in 1988 and only had 1.4 million ESAL at the time of evaluation.

One section compared the effect of positive load transfer devices without a permeable base. Note the benefits of positive load transfer devices.

AVERAGE FAULTING



This chart shows the performance JOINT FAULTING of Jointed Concrete Pavements with positive load transfer. Notice that pavements with positive load transfer devices did not benefit with the addition of permeable bases.

This slide is a little misleading in that it does not show slab cracking or faulting at slab cracks. For example the Missouri 1 project is a JRCP with 60' joint spacings. The section with permeable base had a significantly lower amount of medium and high severity transverse cracks in slabs than the sections constructed on dense graded aggregate bases.

PRELIMINARY FINDINGS

- Less faulting with permeable bases
- Reduction in faulting more profound for nondoweled pavements
- No difference in type of permeable base
- Interior slab deflections same
  - Higher corner deflections for nondoweled pavements

(continued)

Preliminary findings from this evaluation are:
- Less faulting with permeable bases.
- There is a reduction in faulting more profound for non doweled pavements.
- No difference in type of permeable base.
- Interior slab deflections same.
- Higher corner deflections for nondoweled sections

PRELIMINARY FINDINGS

(continued)

- Backcalculated k values same
- Maximize effectiveness
  - Permeable base directly under slab
  - Provide filter (separator) layer

PRELIMINARY FINDINGS

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IMPORTANT FACTORS

- Permeable base directly beneath slab
- Provide filter layer (or fabric)
- Proper location of edgedrain
- Slab and joint design

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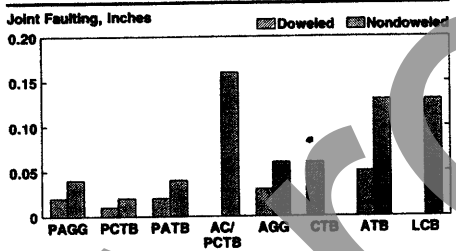
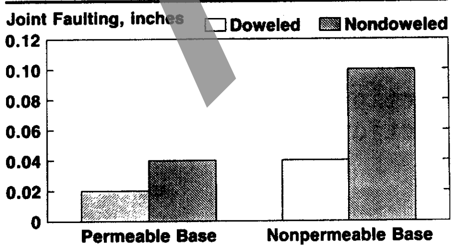
- Slab and joint design

AVERAGE FAULTING BASE TYPE & LOAD TRANSFER

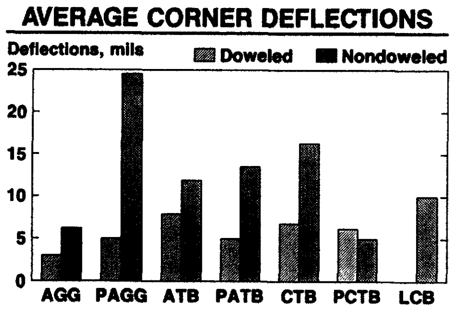


This slide shows average joint faulting by base type and load transfer. There is a direct benefit from the use of load transfer devices. It also appears that the average faulting on permeable base sections is at least half of the average of the dense graded sections.

AVERAGE FAULTING PERMEABLE & NONPERMEABLE BASES



Average joint faulting for permeable and nonpermeable base sections. Again notice the benefit using the permeable base and positive load transfer devices.



Average corner deflections for doweled and nondoweled sections per base type.