STRUCTURAL DESIGN OF PERMEABLE PAVEMENTS WORKSHEET

There are four key elements to the structural design of Permeable Pavements:

1. Total Traffic
2. In-Situ Soil Strength
3. Environmental Elements
4. Actual Layer Design

The first three elements are inputs into the fourth, Layer Design.

A. Total Traffic

Determining total traffic, or expected vehicle load placed on the pavement, is a five step process.

1. Estimate Vehicle Weight
2. Number of Vehicle Passes (Average Daily Traffic)
3. Converting Vehicle Weight to Established Factor
4. Decide Design Life
5. Calculate Total Expected Load

1. Estimating Vehicle Weight:
   For cases examined for Permeable Pavement, it can be expected that either only cars and other passenger vehicles would be used or, for the case of a fire lane, a large vehicle, such as a fire truck would use the pavement occasionally.
   Call this value **Design Weight**, *DW*.

2. Number of Vehicle Passes:
   Most permeable pavements will have vehicles pass over them from 4 to 100 times per day, depending on the pavement type and expected use. Number of vehicle passes is not simply the number of cars expected to use the lot on a daily basis. Each vehicle will have to enter and leave. Many vehicles may make more than 1 trip to the lot in a given day.
   Call this value **Number of Passes**, *N*.

3. Converting Vehicle Weight to Established Factor:
   For engineering design purposes it is necessary to convert weight to an established factor. This has traditionally meant equivilating the vehicle weight from #1 to a measure of 18,000 lbs, or 18 kips. The following formula is used:

   F_j (conversion factor) = **Equivalent Axle Load**, $EAL = (18/DW)^4$

4. Decide Design Life:
   Most permeable pavement applications will have life spans ranging from 10 to 20 years. As a rule a conservative value for design life would be 10 years.

   Call this value **Design Life**, *DL*.

5. Calculating Total Expected Vehicle Load:
The expected Vehicle Load is a function of the previously calculated parameters:
Equivalent Axle Load, EAL (note: based upon Design Weight, DW)
Number of Vehicle Passes, N (in vehicles/day)
Design Life, DL (in years)

The following formula is used:

(N)*(365 days/year)*$(DL)/EAL$ = **Total ESALs** = Total Expected Vehicle Load

EXAMPLE CALCULATION:
Given: Lightly used parking lot for employees. Expect 10 vehicles per day to enter & exit. 50% of drivers will make 2 trips per day.
Find: Expected Vehicle Load in ESALs

i. Design Weight: 4000 lbs (4 kips). This is the size of an SUV. No trucks are expected on the parking lot. **DW=4 kips**

ii. Number of Vehicle Passes: 30. 10 vehicles X 2 for entering and exiting. Multiply by 1.5 to incorporate repeat traffic. 10 X 2 X 1.5 = **N = 30.**

iii. Convert Vehicle Weight to EALs for engineering use:
F_j (conversion factor) = $(18/4)^4$ = **410 Equivalent Axle Loads (EALs)**
For general purposes, 400 vehicle passes of a 4 kip vehicle is equivalent to one pass of an 18 kip vehicle.

iv. Design Life: 10 years. Conservative estimate in 10-20 year range appropriate for permeable pavements. **DL = 10**.

v. Calculate Total Expected Vehicle Load:
(30 vehicles/day)*(365 days/year)*(10 years)/400 vehicles = **275 total ESALs**
The **275 total ESAL** *weight value will be used when calculating layer thickness at the end of this handout.*

B. In-Site Soil Strength

In-situ soil strength varies by soil type. Fortunately, soils that are highly permeable (such as sands, loamy sands, and sandy loams) also have the best bearing capacity (ability to carry loads).
Calculating soil strength is a three step process:
1. Determine Soil Type
2. Estimate Base Strength
3. Convert to Soil Support Value

1. Determine Soil Type:
   For simple applications the county Soil Survey available from Cooperative Extension or the Soil & Water Conservation District can be used. If a more accurate soil characterization is needed field tests may be needed.

2. Estimate Base Strength:
   Engineering calculations for base strength do not use USDA soil textures as inputs. In stead, the Unified Series Classification System (USCS) is used. Table 1 can be used to "convert" USDA soil textures to the USCS classification.

Table 1 – Relating USDA Soil Texture with USCS

USDA Soil Texture	USCS Equivalent
Sand	SW & SP
Loamy Sand	SM
Sandy Loam	SM-ML

USCS Soil Types have a typical range of strength, or Bearing Capacity. One measure of this capacity is the California Bearing Ratio (**CBR**). Values for **CBR** are given for the four USCS Soil Types listed in Table 2. The higher the **CBR** the stronger the soil's strength. For estimates used for permeable pavements, a conservative (lower) number should be used. If a detailed number is required, the soil should be field tested.

Table 2 – California Bearing Ratio Ranges as a function of USCS Classification

USCS Classification	California Bearing Ratio (CBR)
SW	20-40
SP	10-40
SM	15-40
ML	5-15

Once the **CBR** is known, the Soil Support Value (**SSV**) can be calculated.

3. Converting to Soil Support Value:
   This is a simple conversion done using Figure 1 on the following page.
   The CBR is simply a proxy for the SSV (& vice-versa).

   The **Soil Support Value, SSV**, *will be used to calculate layer thickness in the last section of this handout.*

EXAMPLE CALCULATION:
Given: Union Point Park in New Bern is a possible site for an application of permeable pavement. It is unknown if the soil type is strong enough to handle occasional loading.
Find: The Soil Support Value for this site.

i. Determine Soil Type: **Seabrook, Sc**. From Map #12 of Craven Soil Survey (see handout on Page 5).

Figure 1 – Converting CBR to SSV

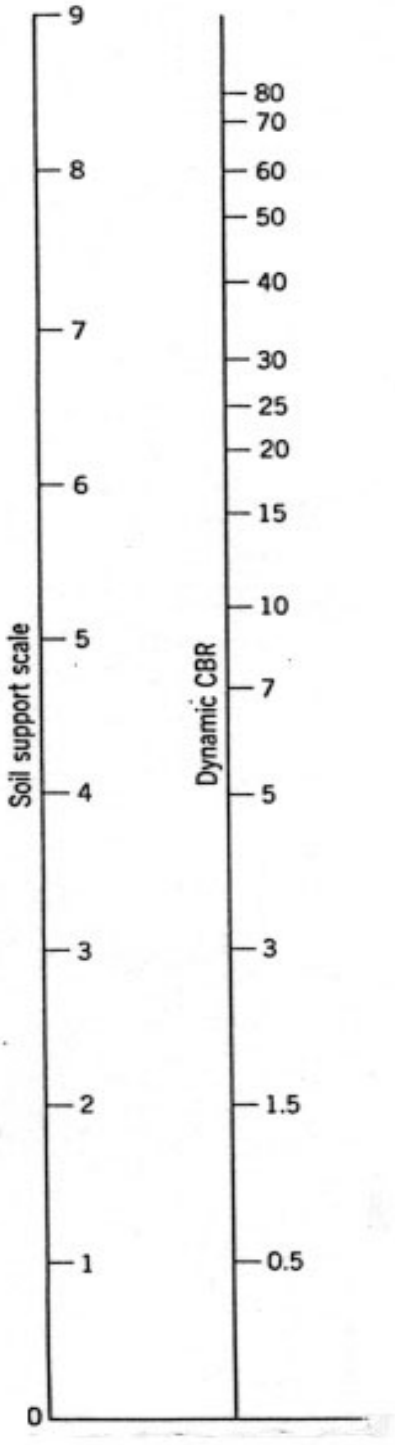
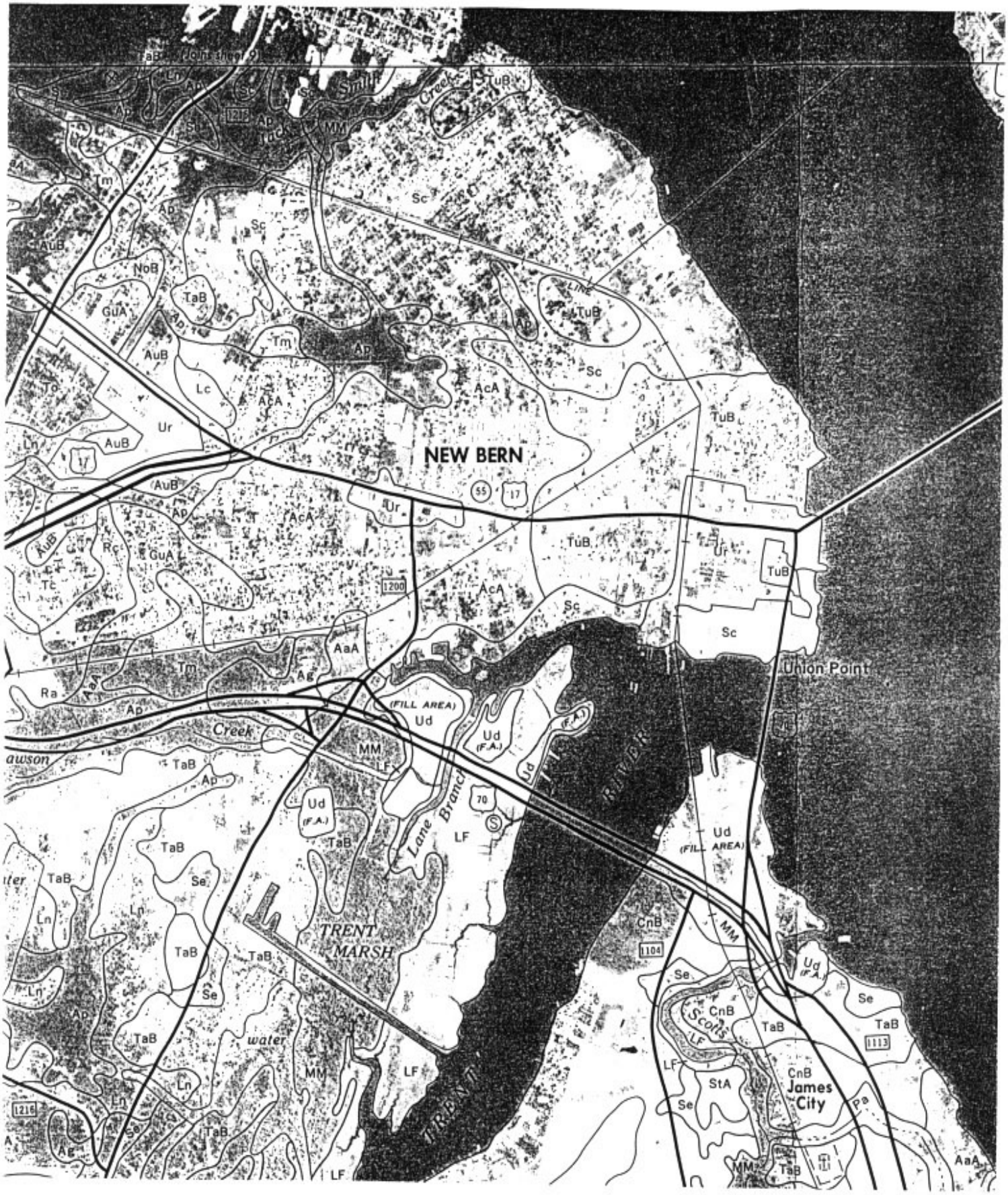


Figure 2 – Soil Survey Map of Craven County



ii. Estimate Soil Strength: From Soil Survey, Sc Soil Series is Loamy Fine Sand & Sand with a USCS Soil Classification of SM, SP-SM. (Figure 3 – page 7)

This USCS Soil Classification should range between 15 and 40 (from Table 2). A conservative estimate to use is for CBR is 20.

iii. Convert CBR to Soil Support Value (SSV): 6.2. From Figure 1, the conversion to SSV is simple. A CBR of 20 is roughly equal to 6.2.

C. Environmental Factors

There are two environmental dependant variables that influence pavement design.
1. The amount and frequency of rainfall, and
2. The ability of the underlying soil to infiltrate water.

Table 3 qualitatively classifies drainage conditions possible with permeable pavements. The most appropriate classification should be used for the design.

Table 3 – Classifying Drainage Condition (ability for soil to infiltrate)

Drainage Condition	**Water Removed Within…**
Excellent	2 hours
Good	1 day
Fair	1 week

With drainage condition selected the amount and frequency of rainfall must be determined. How frequently is the pavement wet? This coupled with the drainage condition determines the Environmental Factor, M. Table 4 shows various values for M as a function of drainage condition and wetness condition.

Table 4 – Determining Environmental Factor, M

Drainage Condition	**Frequency Pavement Base Layer is at Moisture Levels Near Saturation**			
	<1%	**1% - 5%**	**5% - 25%**	**>25%**
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80

Conservative estimates for pavement drainage would lead the designer to select moisture levels of either 5-25% or >25%. It is highly recommended that the drainage condition for soils is either Excellent or Good. The most conservative estimate based upon these 2 set parameters for the Environmental Factor is 1.00 (Good, >25%)

EXAMPLE CALCULATION:
For Eastern North Carolina, which receives rainfall roughly in 1 of 3 days, a moisture level of >25% is possible. Assuming the worst case drainage condition (either excellent or good), the **Environmental Factor, M, of 1.00** is not unreasonable.

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Figure 3 – Craven County Soil Survey: Engineering Index Properties

TABLE 14.--ENGINEERING INDEX PROPERTIES--Continued

Map symbol and soil name	Depth	USDA texture	Classification		Frag-ments > 3 inches	Percentage passing sieve number--				Liquid limit	Plas-ticity index
			Unified	AASHTO		4	10	40	200		
	In				Pct					Pct	
Ro---------- Roanoke	0-11	Fine sandy loam	SM, ML, CL-ML, SM-SC	A-2, A-4	0	85-100	80-100	45-85	25-55	<25	NP-7
	11-15	Clay loam, loam.	CL	A-6, A-7	0	95-100	85-100	80-100	80-95	35-45	14-20
	15-41	Clay, silty clay, clay loam.	CH, CL	A-7	0	90-100	85-100	85-100	65-95	45-70	22-40
	41-80	Variable----------	---	---	---	---	---	---	---	---	---
Sc:											
Seabrook--------	0-6	Loamy sand-------	SM, SP-SM	A-2, A-3	0	95-100	90-100	85-99	5-25	---	NP
	6-80	Loamy fine sand, fine sand, sand.	SM, SP-SM	A-2, A-3	0	95-100	90-100	85-100	5-25	---	NP
Urban land.											
Se---------- Seabrook	0-6	Loamy sand-------	SM, SP-SM	A-2, A-3	0	95-100	90-100	85-99	5-25	---	NP
	6-80	Loamy sand, fine sand, sand.	SM, SP-SM	A-2, A-3	0	95-100	90-100	85-100	5-25	---	NP
StA---------- State	0-13	Loamy sand-------	SM, SM-SC	A-2, A-1	0	95-100	95-100	45-75	15-30	<18	NP-6
	13-38	Sandy clay loam.	CL, SC	A-4, A-6	0	95-100	95-100	75-100	35-80	24-40	8-22
	38-70	Stratified sand to fine sandy loam.	SM, SM-SC, SP-SM	A-1, A-2, A-3, A-4	0	85-100	75-100	40-90	5-50	<25	NP-7
SuD---------- Suffolk	0-14	Loamy sand-------	SM, SM-SC	A-1, A-2, A-4	0	95-100	90-100	40-85	15-40	<18	NP-6
	14-38	Sandy clay loam, clay loam, sandy loam.	SC, CL	A-2, A-6	0	95-100	90-100	50-95	25-75	20-40	10-25
	38-80	Loamy sand, sandy loam, sand.	SP, SM, SM-SC	A-1, A-2, A-3, A-4	0	75-100	75-100	30-80	3-50	<18	NP-7
TaB---------- Tarboro	0-30	Sand----------	SM, SP-SM, SW-SM	A-2, A-3, A-1	0	95-100	85-100	40-99	8-35	---	NP
	30-80	Sand, loamy sand.	SP, SP-SM, SW-SM, SM	A-2, A-3, A-1	0	95-100	90-100	45-100	3-15	---	NP
Tc:											
Torhunta--------	0-12	Fine sandy loam	SM	A-2, A-4	0	100	95-100	70-96	20-49	<25	NP-4
	12-37	Sandy loam, fine sandy loam.	SM, SM-SC	A-2, A-4	0	100	95-100	70-92	20-40	<25	NP-7
	37-80	Loamy sand, sand, sandy loam.	SM, SP-SM, SM-SC	A-2, A-3	0	100	95-100	65-92	5-35	<25	NP-4
Urban land.											
Tm---------- Tomotley	0-11	Fine sandy loam	SM	A-2, A-4	0	98-100	95-100	75-98	25-50	<30	NP-7
	11-41	Fine sandy loam, sandy clay loam, clay loam.	SM-SC, SC, CL-ML, CL	A-2, A-4, A-6	0	98-100	95-100	75-98	30-70	20-40	6-18
	41-80	Variable----------	---	---	---	---	---	---	---	---	---
To---------- Torhunta	0-12	Fine sandy loam	SM	A-2, A-4	0	100	95-100	70-96	20-49	<25	NP-4
	12-37	Sandy loam, fine sandy loam.	SM, SM-SC	A-2, A-4	0	100	95-100	70-92	20-40	<25	NP-7
	37-80	Loamy sand, sand, sandy loam.	SM, SP-SM, SM-SC	A-2, A-3	0	100	95-100	65-92	5-35	<25	NP-4

D. Determining Layer Thickness

To determine layer thickness, the total strength of the pavement must be calculated. This strength is called the Structural Number. The structural number must be matched or exceeded by the strength of the pavement. The strength of the pavement is determined by materials used (such as concrete block, plastic grid, sand, and stone) and the thickness of each layer.

The two steps are
1. Determining Necessary Strength (Structural Number)
2. Setting Layer Thickness so that Structural Number is Met or Exceeded

1. Determining Structural Number (SN):
The structural number (SN) is an engineering figure. It represents the required strength of the pavement. Three factors influence the structural number:
   a. Total Traffic (determined in Part A)
   b. Soil Support Value (determined in Part B)
   c. Serviceability (how much deterioration of the pavement is allowable) (set to 2.0 for low traffic volumes of Permeable Pavements)
   d. A regional environmental factor (which is estimated to be 1.0 for Eastern NC)

   Using these factors as inputs into the Nomograph shown in Figure 4 on Page 9, the necessary strength of the pavement, or SN, is found.

   The pavement must have a calculated Structural Number (SN calc) that is at least as high.

2. Assigning Layer Thickness:
The pavement can be divided into 3 layers:
   a. Top Layer with Permeable Paving Material (1)
   b. Supporting Sand Layer (2)
   c. Gravel base layer (3)

   The material of each layer has preset strengths. Each layer is assigned a coefficient: a1, a2, and a3. These values are given in Table 5 below.

Table 5 – Strength Coefficients

Material	Strength Coefficient
Turfstone Fill	0.40* (from Manf'r) 0.20 is conservative
Sandy Gravel	0.07
Gravel Base	0.14

Figure 5 – Layers of Permeable Pavement

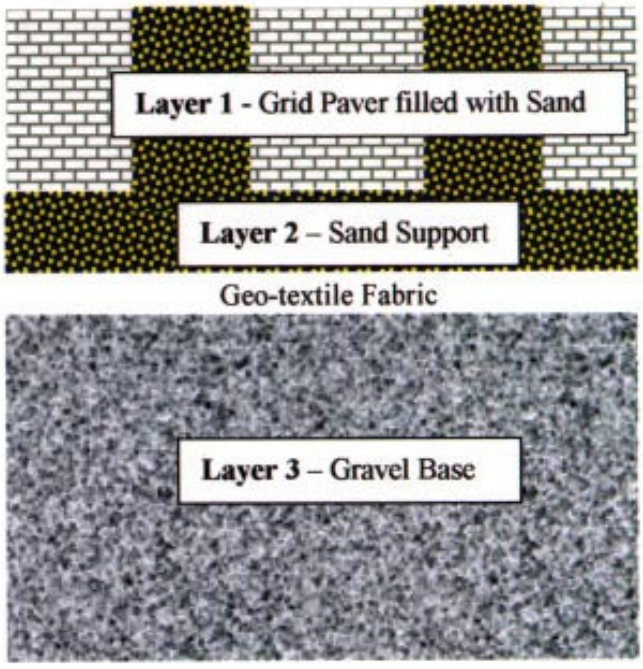
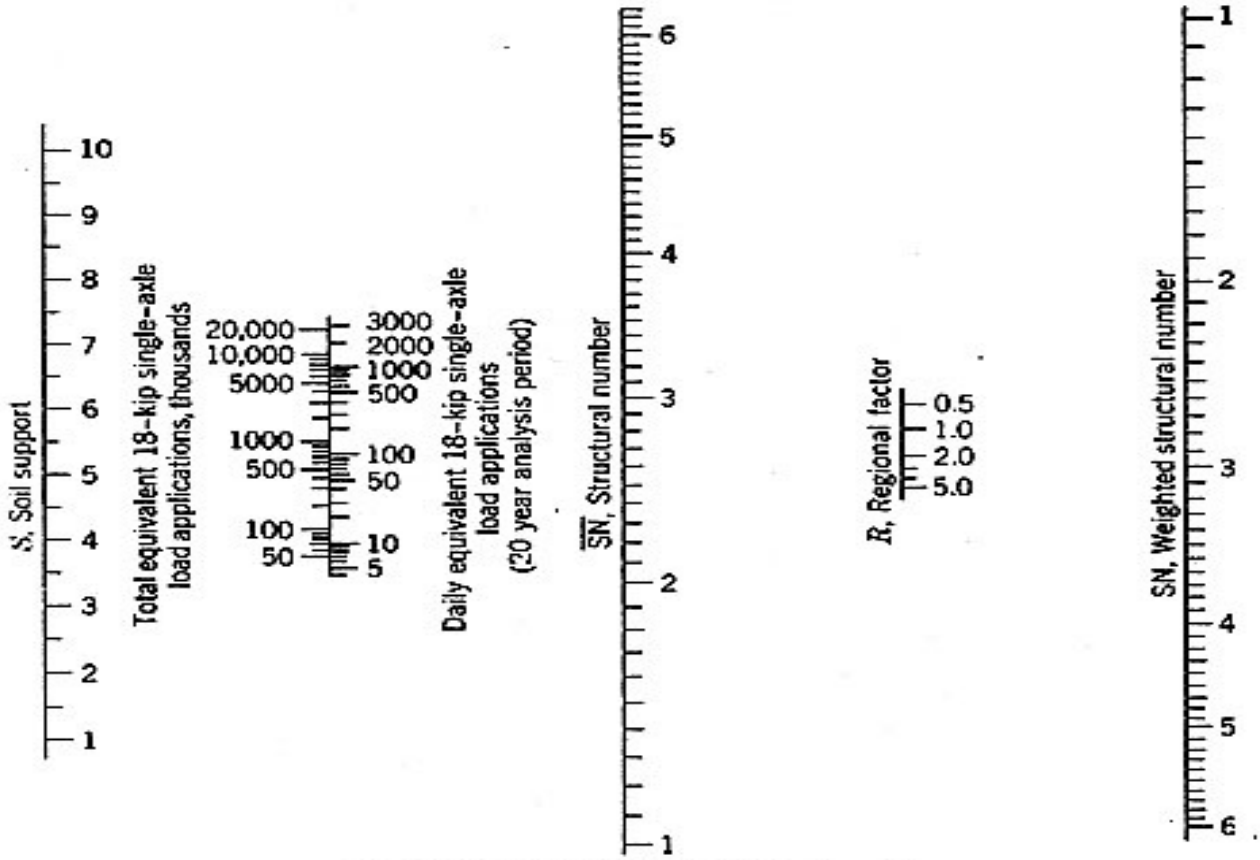


Figure 5 – Nomograph to Determine Structural Number (Pavement Strength)



Design chart for flexible payments, $P_t = 2.0$

The deeper the layers of material the more strength it has. However, layer thickness of layers 1 and 2 of the pavement is pre-determined. The thickness of the layer one is set to that of the paving block being used. (Concrete Block Pavers ~ 3.5", Plastic Grid Pavers ~ 2"). Per manufacturer's recommendation and the demands for grass roots, the Sand support layer (layer 2) should have a depth of 2".
This leaves only one layer, which can have its thickness varied: Layer 3, the gravel base.
The thickness of this layer will determine whether or not the permeable pavement is strong enough (greater than the design SN).

The pavement will have a strength as determined by the following formula which uses layer depth, material strength coefficients, and the environmental factor, **M**, determined in part C:

$$\mathbf{SN_{calc} = a_1D_1 + a_2D_2 + Ma_3D_3}$$

Where: **a1, a2**, and **a3** are strength coeffecients.
D1, D2, and **D3** are layer depths, and
M = Environmental Factor (part C)

D3 is varied until SN calc is at least that of the Design SN as determined from the Nomograph.

If SNcalc > SN (nomograph), design is adequately strong.
If SNcalc < SN (nomograph), design is too weak. Must make rock base thicker.

EXAMPLE CALCULATION:
Given: Parking lot is desired to be made from Concrete Block Pavers. The pavers are to be filled with sand and eventually planted with bermuda grass. Using factors from parts A, B &C of this worksheet, the following values are known:
Total Traffic = 275 ESALs
Soil Support Value = 6.2
Environmental Factor = 1.00

Find: Design Strength (Structural Number, SN) and Appropriate Layer Thickness to meet SN.

Determining Structural Number: By estimating two other factors, serviceability (2.0 is standard) and a regional factor (1.0 for eastern NC), the Nomograph can be used to determine necessary strength (Structural Number). **A SN of 1.9 was found.**

Selecting Layer Thickness: The following parameters are used to determine a Calculated SN (SN calc):
A1 – 0.25, A2 – 0.07, A3 – 0.14, D1 – 3.5", D2 – 2", D3- 8", M-1.00

By inserting into formula: $\mathbf{SN_{calc} = a_1D_1 + a_2D_2 + Ma_3D_3}$

The following SN is calculated: 0.25 (3.5) + 0.07 (2) + 1.00 (0.14) (8) = 2.1

SN calc > SN (nomograph) => 2.1 > 1.9,

Therefore, Pavement Design is OK. Do not need to increase Pavement Thickness. (In fact, a 7 inch layer for D3 is acceptable.)

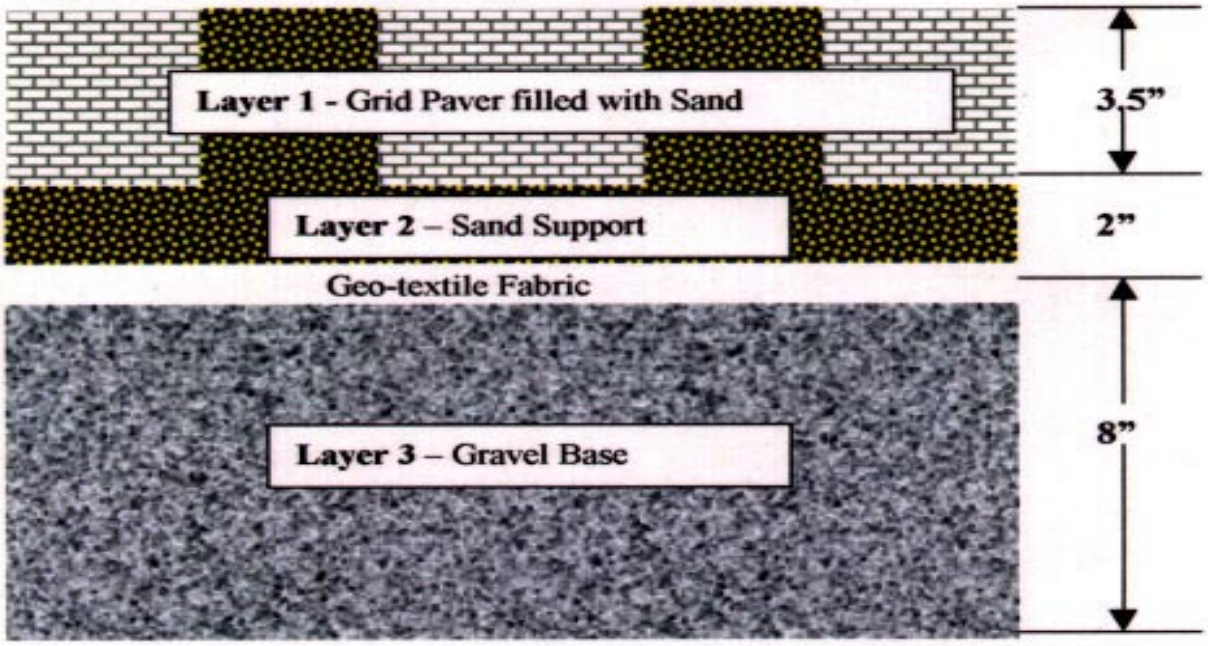



Figure 6 – Layers Thickness for Final Design