C. Material Properties for Structural Design

Layer Coefficients for

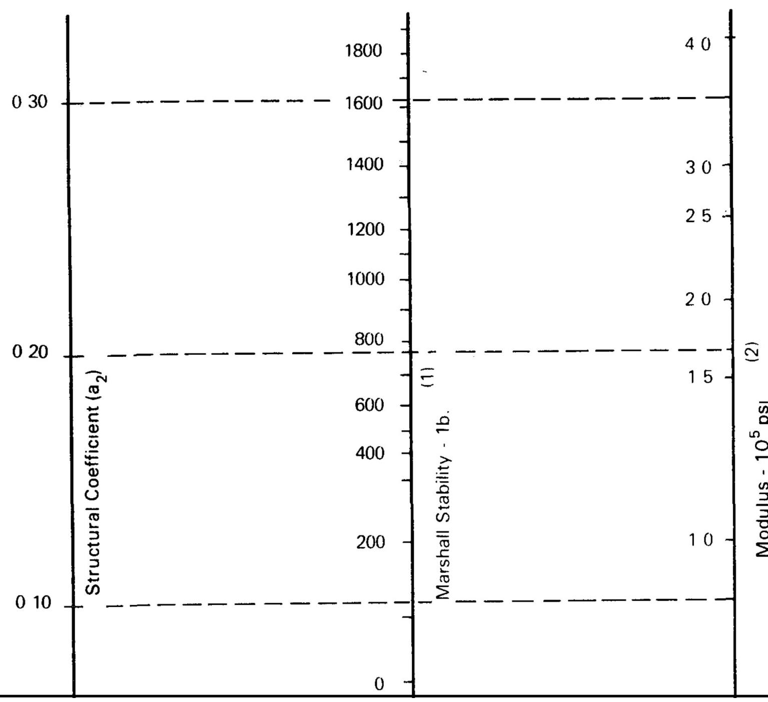
Treated Base Layers

95

Determination of base coefficient (a_2)

Higher a_2 coefficient indicate better base materials

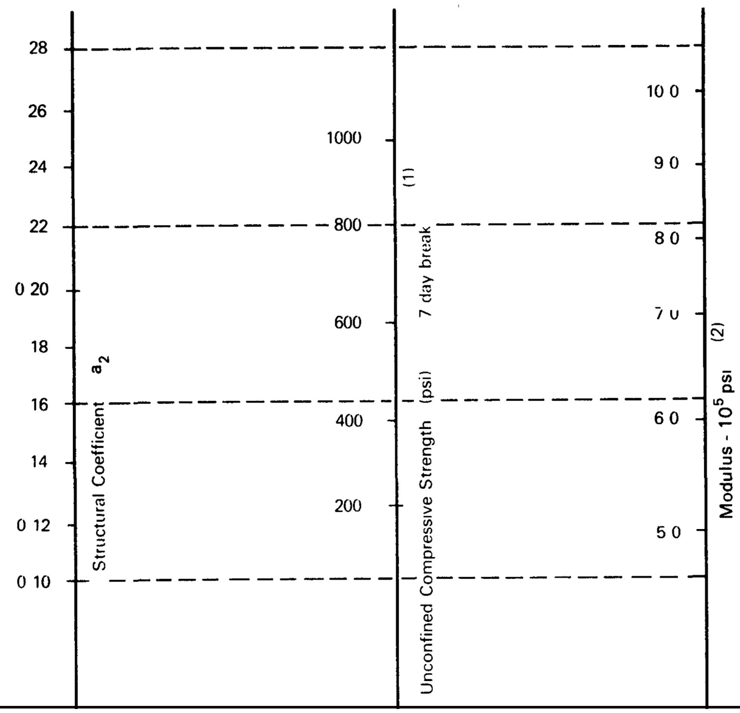
Bituminous-Treated base



Determination of base coefficient (a_2)

Higher a_2 coefficient indicate better base materials

Cement-Treated base



C. Material Properties for Structural Design

Layer Coefficients for

Granular SubBase Layers

98

Granular Base Layers

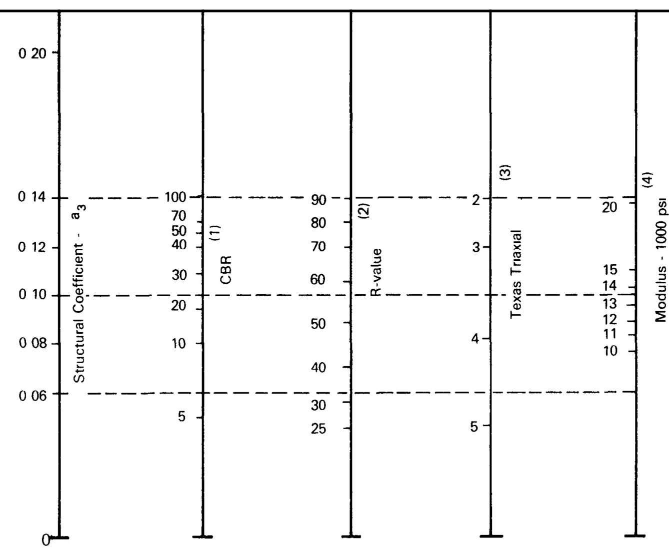
Layer Coefficient

- **Quality of the SubBase**
  - *Determined in terms of the **layer coefficient (a3)**.*
- **Definition of a_3:**
  - *measures the **relative effectiveness** of the subbase material as a structural component of the pavement.*
  - *Converts the **actual thickness** of the base into an **equivalent Structural Number (SN)**.*
  - *Reflects the **strength contribution** of the material in pavement design.*
- **How to get a_3**
  - *Figure 2.7 provides a chart that may be used to estimate a structural layer coefficient ($a2$) from one of four different laboratory test results on a granular base material, including the base resilient modulus (EB).*

Determination of Subbase coefficient (a_3)

Variation in Granular Subbase Layer Coefficient, a_3, with Various Subbase Strength Parameters

Higher a_3 coefficient indicate better subbase materials



(1) Scale derived from correlations from Illinois
(2) Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico and Wyoming
(3) Scale derived from correlations obtained from Texas
(4) Scale derived on NCHRP project *(3)*

Figure 2.7. Variation in Granular Subbase Layer Coefficient (a_3) with Various Subbase Strength Parameters (*3*)

D. Pavement Structural Characteristics

Drainage

101

Introduction

- Impact of Water Infiltration:
  - *Weakening of base material and subgrade.*
  - *Loss of strength in base and roadbed soils.*
  - *Increased deformation and cracking.*
- What is Drainage in Pavements?
  - *The process of removing water from the pavement structure to maintain its performance and durability.*
- Objectives of Pavement Drainage
  - *Provide rapid removal of free water from the pavement structure.*
  - *Minimize moisture variations in base and subgrade layers.*
  - *Enhance pavement durability and performance.*

Components of Pavement Drainage System

- Surface Drainage:
  - *Removes water from the pavement surface.*
  - *Features: Slope design, curb, and gutter systems.*
- Subsurface Drainage:
  - *Eliminates water infiltrating into the pavement structure.*
  - *Components: Perforated pipes, drainable base layers, geotextiles.*

Consideration of Drainage effect

Modifying the structural layer coefficient

- Modifying the structural layer coefficient ***(a_2 and a_3)***
  - *The modification is carried out by incorporating a factor* ***m_i*** *for the base and subbase layer coefficients (a_2 and a_3)*
  - *The m_i factors are based on*
    1. The percentage of time during which the pavement structure will be nearly saturated
    2. The quality of drainage,
       - *which is dependent on the time it takes to drain the base layer to 50 percent of saturation.*

Drainage

Modifying the structural layer coefficient.

The general definitions of the different levels of drainage quality

Table 19.5 Definition of Drainage Quality

Quality of Drainage	*Water Removed Within**
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very poor	(water will not drain)

*Time required to drain the base layer to 50% saturation.

Drainage

Modifying the structural layer coefficient.

Recommended m_i values for different levels of drainage quality

Table 19.6 Recommended m_i Values

Quality of Drainage	*Percent of Time Pavement Structure Is Exposed to Moisture Levels Approaching Saturation*: *Less Than 1%*	*1 to 5%*	*5 to 25%*	*Greater Than 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
Poor	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very poor	1.05–0.95	0.95–0.75	0.75–0.40	0.40

Example 2

- A flexible pavement for an urban interstate highway is to be designed using the 1993 AASHTO guide.
- It is estimated that it takes about a week for water to be drained from within the pavement and the pavement structure will be exposed to moisture levels approaching saturation or 30% of the time f
- Determine
  - ➢The appropriate drainage coefficient m_i.

Solution

- A flexible pavement for an urban interstate highway is to be designed using the 1993 AASHTO guide.
- It is estimated that it takes about a week for water to be drained from within the pavement and the pavement structure will be exposed to moisture levels approaching saturation or 30% of the time
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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
Poor	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very poor	1.05–0.95	0.95–0.75	0.75–0.40	0.40

Design steps

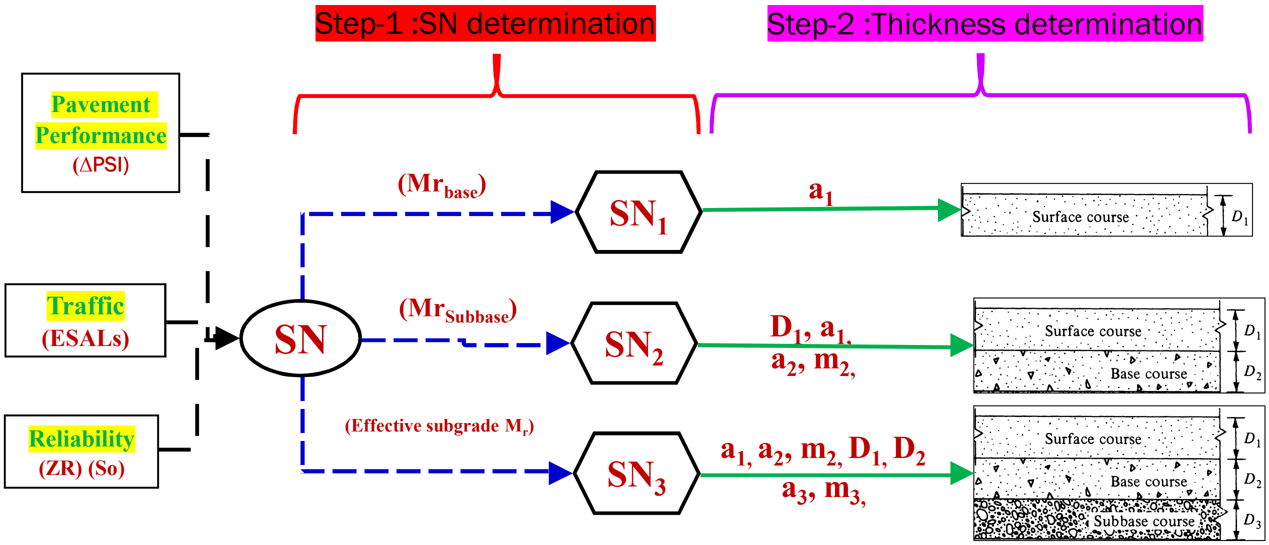
Design steps

- ***Step A:***
  - *Determine the Structural Number (SN) for pavement layers*
    - SN_1 = The structure number require to protect base layer
    - SN_2 = The structure number require to protect subbase layers
    - SN_3 = The structure number require to protect (roadbed) subgrade layer
- ***Step B:***
  - *Estimate the required layers thickness based on SNs values*

Design steps

Step A: *Determine Structural Number (SN) for pavement layers*

$$\log_{10}W_{18} = Z_R S_o + 9.36\log_{10}(\text{SN}+1) - 0.20 + \frac{\log_{10}[\Delta\text{PSI}/(4.2-1.5)]}{0.40+[1094/(\text{SN}+1)^{5.19}]} + 2.32\log_{10}M_r - 8.07 \quad (19.7)$$



AASHTO 1993 design method

Basic Design Equation

$$\log_{10} W_{18} = Z_R S_o + 9.36 \log_{10}(\mathrm{SN} + 1) - 0.20 + \frac{\log_{10}[\Delta \mathrm{PSI}/(4.2 - 1.5)]}{0.40 + [1094/(\mathrm{SN} + 1)^{5.19}]} + 2.32 \log_{10} M_r - 8.07 \qquad (19.7)$$

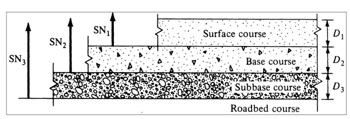
- W_{18} = predicted number of 18,000-lb (80 kN) single-axle load applications
- Z_R = standard normal deviation for a given reliability
- S_o = overall standard deviation
- SN = structural number indicative of the total pavement thickness
- $\Delta PSI = p_i - p_t$
- p_i = initial serviceability index
- p_t = terminal serviceability index
- Mr = Subgrade effective resilient modulus lb/in^2

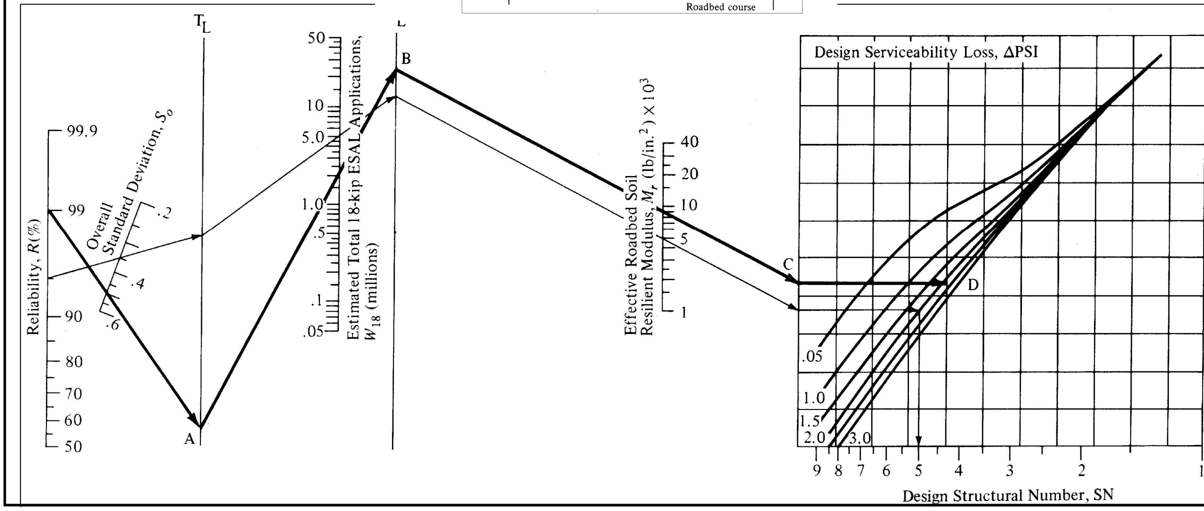
SN determenatio

Structural Number (SN)

Basic Design Equation

- There are three type of SN
  - ➢ SN_1 = *The structure number require to protect base layer*
  - ➢ SN_2 = *The structure number require to protect subbase layers*
  - ➢ SN_3 = *The structure number require to protect (roadbed) subgrade layer*





Example No.1

Part A: Determine SN for different pavement layers .

SN determenation

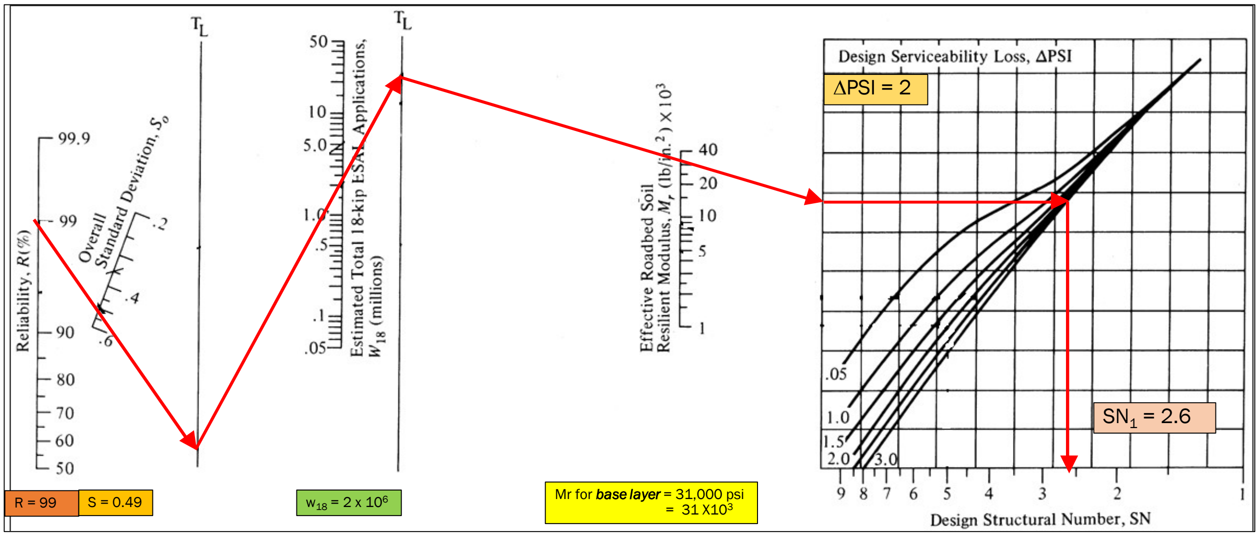
Example 2.

- A flexible pavement for an urban interstate highway.
- Cumulative ESAL = 2x 10^6
- Reliability = 99
- Standard deviation (*So*) = 0.49
- Initial PSI = 4.5
- Terminal PSI = 2.5
- ΔPSI = 2
- Resilience modulus of asphalt concrete = 450,000 psi.
- Base course: CBR = 100 , Mr = 31,000 psi
- Subbase course: CBR = 22, Mr = 13,500 psi
- Subgrade: CBR = 6
  - *Mr = 9,000 PSi*

Determine SN for different pavement layers .

Example 2 solution

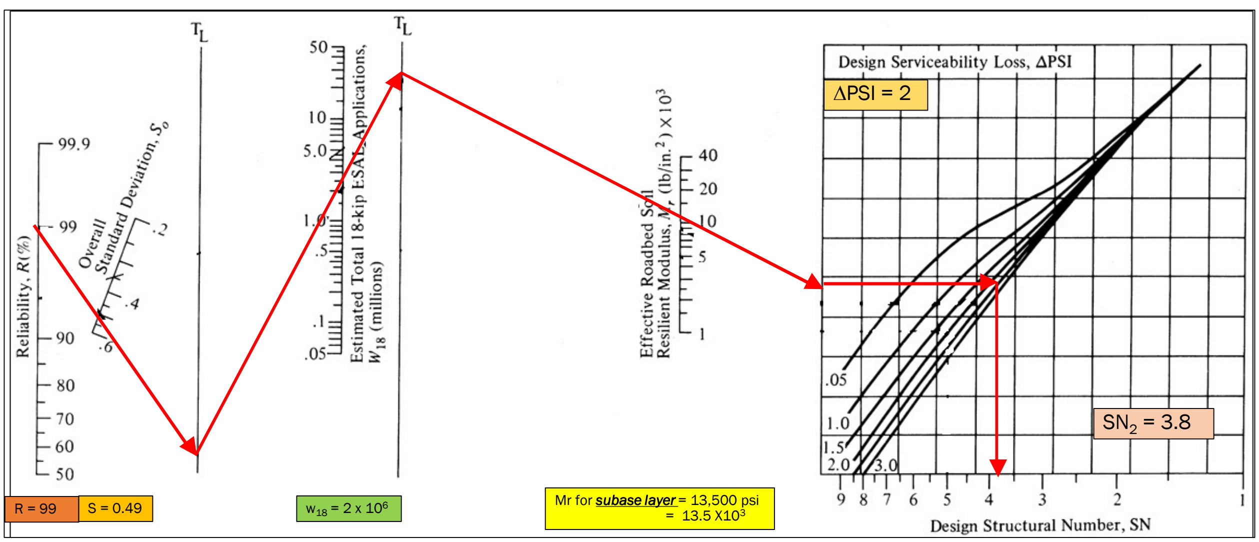
Determination of SN_1 (to protect base layer)



Follow the red line

Example 2 solution

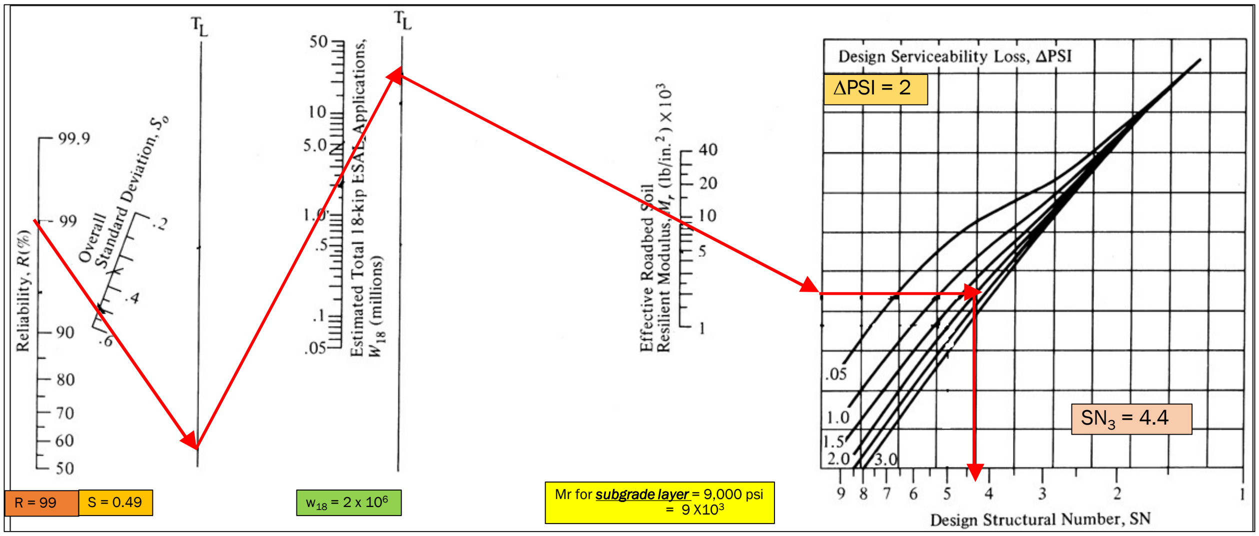
Determination of SN_2 (to protect subase layer)



Follow the red line

Example 2 solution

Determination of SN_3 (to protect Subgrade layer)



Follow the red line

Part B:
Estimate the required layers thickness based on SNs values.

Design steps

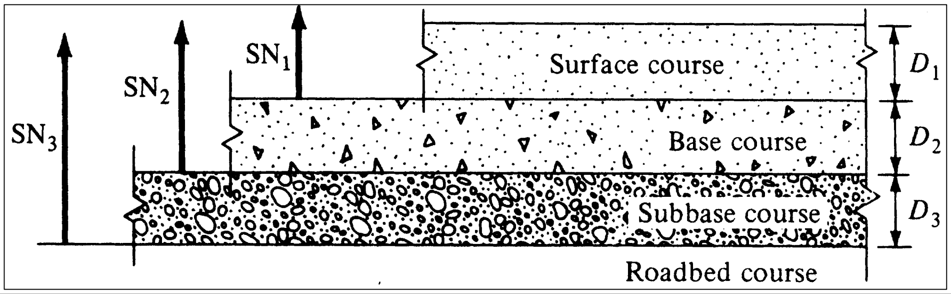
Step B: Selection of Layer thickness

Structure Design

Structural Number (SN)

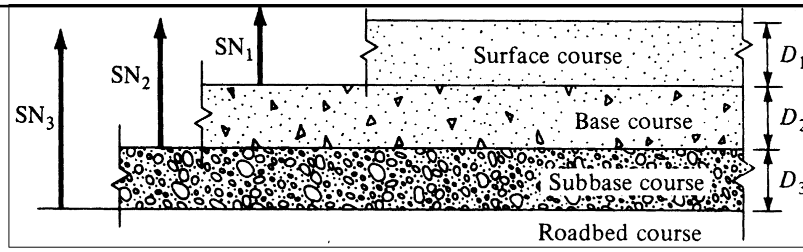
$$SN = SN_1 + SN_2 + SN_3$$

- There are three type of SN
  - ➢ *SN_1 = The structure number require to protect base layer*
  - ➢ *SN_2 = The structure number require to protect subbase layers*
  - ➢ *SN_3 = The structure number require to protect (roadbed) subgrade layer*



Structure Design

Structural Number (SN)

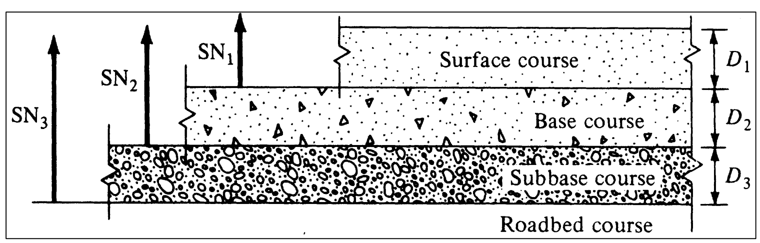


- SN_1 = The structure number require to protect base layer

$$SN_1 = a_1 D_1$$

- a_1: Layer coefficient for the surface layer.
- D_1: Thickness of the surface layer (in inches).

Relation between SN and layers thickness

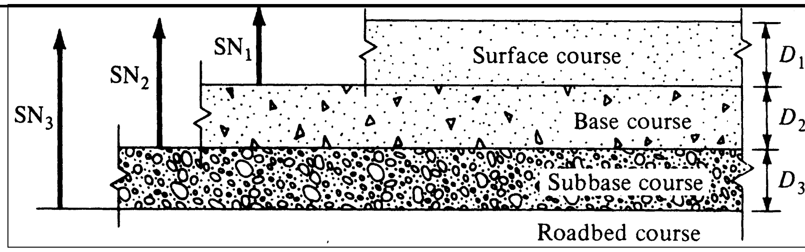


- $D_1 \geq \frac{SN_1}{a_1}$

  - *Where*
    - SN_1 = The structure number require to protect base layer
    - D_1 = Actual thickness in inches of surface
    - a_1 = layer coefficients representative the quality of surface, course,

Structure Design

Structural Number (SN)



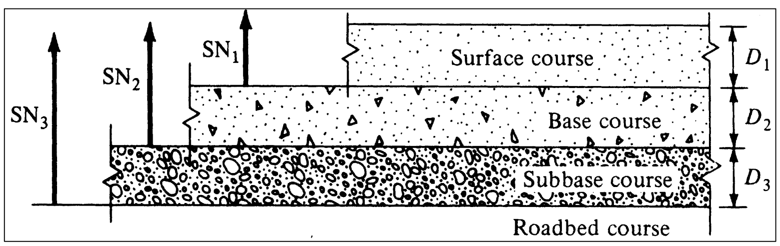
- SN_2 = The structure number require to protect Subbase layer

$$SN_2 = a_1 D_1 + a_2 m_2 D_2$$

$$SN_2 = SN_1 + a_2 m_2 D_2$$

Relation between SN and layers thickness

- $D_2 \geq \frac{SN_2 - S_{\ 1}}{a_2 m_2}$
- $D_2 \geq \frac{SN_2 - a_2 D_1}{a_2 m_2}$

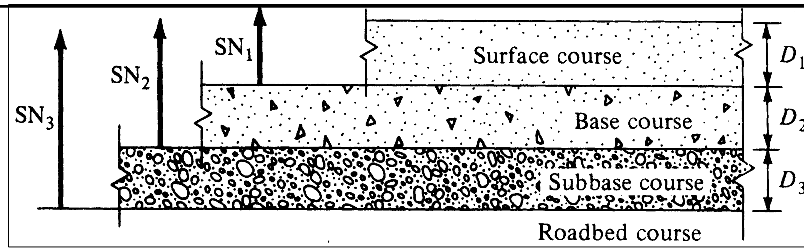


➢ *Where*

- SN_1 = The structure number require to protect base layer
- D_2 = actual thickness in inches of base
- a_2 = layer coefficients representative the quality of base,,
- m_2 = drainage coefficient for layer *base*

Structure Design

Structural Number (SN)



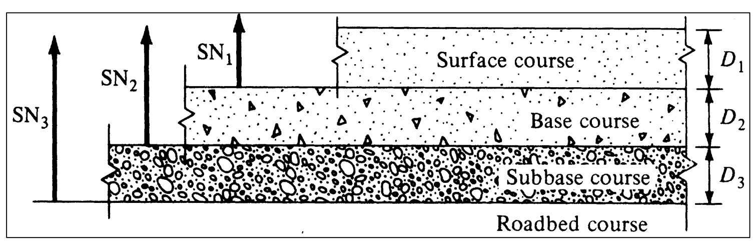
- SN_3 = The structure number require to protect Subgrade layer

$$SN_3 = SN_1 + SN_2 + a_3 m_3 D_3$$

$$SN_3 = a_1 D_1 + a_2 m_2 D_2 + a_3 m_3 D_3$$

Relation between SN and layers thickness

- $D_3 \geq \frac{SN_3 - SN_2 - S_1}{a_3 m_3}$
- $D_3 \geq \frac{SN_3 - a_2 m_2 D_2 - a_1 D_1}{a_3 m_3}$



➢ *Where*

- ❖ SN_1 = The structure number require to protect base layer
- ❖ D_3 = actual thickness in inches of subbase
- ❖ a_3 = layer coefficients representative the quality of subbase, course,
- ❖ m_3 = drainage coefficient for layer *subbase*

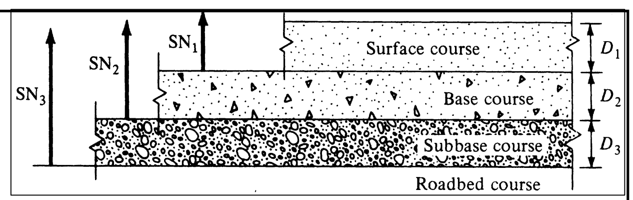
Design steps

Step B: Selection of Layer thickness

Procedures

Step-2 :

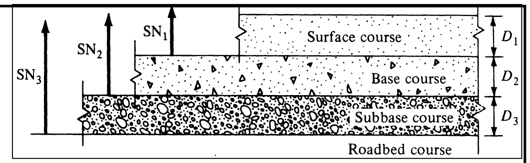
Procedures



- **Step 2.3** :
  - *Using the structural number SN_1 and a_1 compute the thickness of layer 1 (D_1)*
- $D_1 \geq \frac{SN_1}{a_1}$
- **Step 2.2** :
  - *Round the calculated (D_1) to the nearest 0.5 in*
  - *Call this value (D_1^*)*

Step-2 :

Procedures



- **Step 2.3** :

  ➢ *Using the structural number SN_2, D_1^*, a_1, a_2, m_2 compute the thickness of layer 2 (D_2)*

- $$D_2 \geq \frac{SN_2 - a_1 \times D_1^*}{a_2 m_2}$$

- **Step 2.4** :

  ➢ *Round the calculated (D_2) to the nearest 0.5 in*

  ➢ *Call this value (D_2^*)*

Step-2 :

Procedures

- **Step 2.5** :

  ➢ *Check the minimum thickness requirement for the surface course and base course*

  ➢ *Called the selected values*

  ❖ D_1^{**}

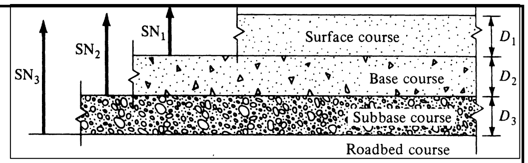
  ❖ D_2^{**}

Table 19.9 AASHTO-Recommended Minimum Thicknesses of Highway Layers

	Minimum Thickness (in.)	
Traffic, ESALs	*Asphalt Concrete*	*Aggregate Base*
Less than 50,000	1.0 (or surface treatment)	4
50,001–150,000	2.0	4
150,001–500,000	2.5	4
500,001–2,000,000	3.0	6
2,000,001–7,000,000	3.5	6
Greater than 7,000,000	4.0	6

Step-2 :

Procedures



- **Step 2.6** :
  - ➢ *Using the structural number SN_2, D_1^*, a_1 compute the thickness of layer 2 (D_2)*
- $D_3 \geq \frac{SN_3 - a_1 \times D_1^{**} - a_2 \times D_2^{**}}{a_3 m_3}$
- **Step 2.7** :
  - ➢ *Round the calculated (D_3) to the nearest 0.5 in*
  - ➢ *Call this value (D_3^*)*

Step-2 :

Procedures

- Report the selected values
- D_1^{**}
- D_2^{**}
- D_3^*

Example

Part B:
Estimate the required layers thickness based on SNs values.

Pavement layer thickness

Example 2

- A flexible pavement for an urban interstate highway.
- ESAL = 2x 10^6
- Reliability = 99
- Standard deviation (*So*) = 0.49
- Initial PSI = 4.5
- Terminal PSI = 2.5
- ΔPSI = 2
- It is estimated that it takes about a week for water to be drained from within the pavement
- The pavement structure will be exposed to moisture levels approaching saturation for 30% of the time.

- Resilience modulus of asphalt concrete = 450,000 psi.
- Base course: CBR = 100 , Mr = 31,000 psi
- Subbase course: CBR = 22, Mr = 13,500 psi
- Subgrade: CBR = 6
  - *Mr = 9,000 PSi*

Determine the thickness of pavement layers .

Equivalent Single Axle Loads (ESALs)

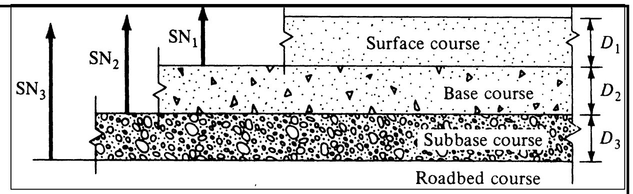
- Step 1.1 :
  - *Determine SN for different layers*
    - $SN_1 = 2.6$
    - $SN_2 = 3.8$
    - $SN_3 = 4.4$

Equivalent Single Axle Loads (ESALs)

- Step 1.2 :
  - *Determine layer coefficients*
    - $a_1 = 0.44$
    - $a_2 = 0.14$
    - $a_3 = 0.1$
    - $m_2 = 0.8$
    - $m_3 = 0.8$

Step-2 :

Procedures



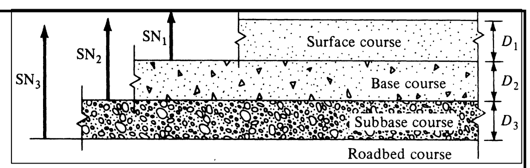
- **Step 2.1** :
  - *Using the structural number SN_1 =2.6 and a_1 = 0.44 compute the thickness of layer 1 (D_1)*

- $D_1 \geq \frac{SN_1}{a_1} = \frac{2.6}{0.44} = 5.9\ in$

- **Step 2.2** :
  - *Round the calculated (D_1) to the nearest 0.5 in*
  - *Call this value (D_1^*)*
  - *D_1^* = 6.0 in*

Step-2 :

Procedures



- **Step 2.3** :
  - *Using the structural number SN_2, D_1^*, $a_1$compute the thickness of layer 2 (D_2)*

- $D_2 \geq \frac{SN_2 - a_1 \times D_1^*}{a_2 m_2} = \frac{3.8 - 0.44 \times 6.0}{0.14 \times 0.8} = 10.36$

- **Step 2.4** :
  - *Round the calculated (D_2) to the nearest 0.5 in*
  - *Call this value (D_2^*)*
  - *D_2^* = 10.50 in*

Step-2 :

Procedures

- **Step 2.5** :

  ➢ *Check the minimum thickness requirement for the surface course and base course*

  - ❖ D_1^* = 6.0 in
  - ❖ D_2^* = 10.50 in

ESAL = 2x 10^6

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	Minimum Thickness (in.)	
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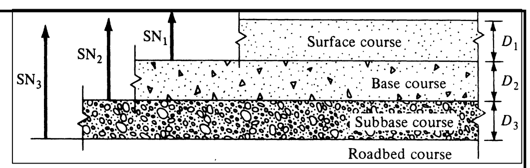
150,001–500,000	2.5	4
500,001–2,000,000	3.0	6
2,000,001–7,000,000	3.5	6
Greater than 7,000,000	4.0	6

  ➢ *Called the selected values*

  - ❖ D_1^{**} = 6.0 in
  - ❖ D_2^{**} = 10.5 in

Step-2 :

Procedures



- **Step 2.6** :

  ➢ *Using the structural number SN_2, D_1^*, a_1 compute the thickness of layer 2 (D_2)*

- $D_3 \geq \frac{SN_3 - a_1 \times D_1^{**} - a_2 \times D_2^{**}}{a_3 m_3} = \frac{4.4 - 0.44 \times 6.0 - 0.14 \times 10.5}{0.1 \times 0.8} = \frac{.29}{0.08}$ = 3.625

- **Step 2.7** :

  ➢ *Round the calculated (D_1^*) to the nearest 0.5 in*

  ➢ *Call this value (D_3^*)*

  ➢ *D_3^* = 4.0 in*

Step-2 :

Procedures

- Report the selected values
- $D_1^{**} = 6\ in\ \ (15.24\ cm)$
- D_2^{**} = 10.5 in $(26.67\ cm)$
- D_3 = 4 in $(10.2\ cm)$