Pavement Materials & Design

Pavement Structure Design

AASHTO 1993 Method

Highway Materials

References

- AASHTO Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials. Washington, D.C.
- Nicholas Garber and Lester Hoel ,***Traffic & Highway Engineering***, 5th Edition.. Cengage Learning, 2015
- Michael S. Mamlouk and JohnP, Zaniewski, ***Traffic & Highway Engineering***, 3th Edition.. Pearson, 2011
- Yang Huang, ***Pavement Analysis and Design***,, 1993
- A. T. Papagiannakis and Eyad A Masad, ***Pavement Design and Materials***, 2008
- https://pavementinteractive.org/

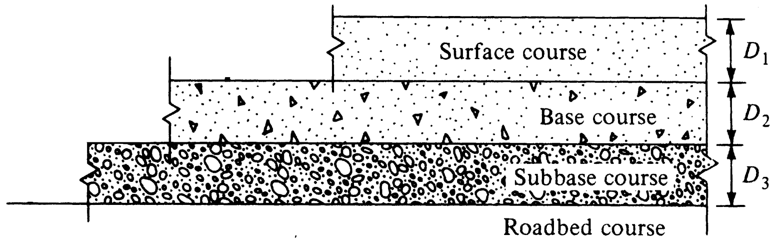
Introduction

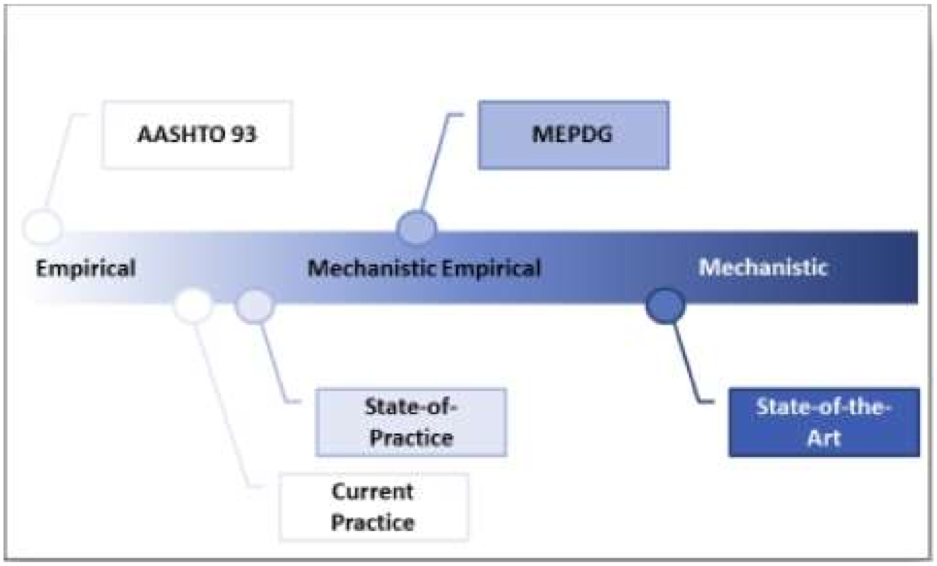
Pavement structure design

Goal

■ The goal of structural design is to determine

- ➢ *The number, material composition and thickness of the different layers within a pavement structure required to accommodate a given loading regime*
- ➢ *This includes the surface course as well as any underlying base or subbase layers*

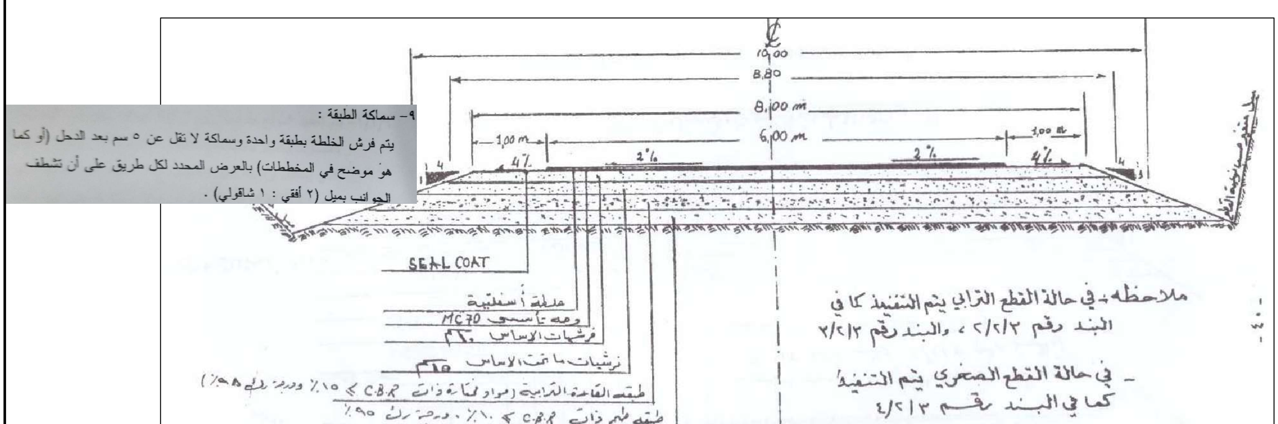




https://www.fhwa.dot.gov/pavement/materials/hmec/pubs/module_e/participant_workbook.pdf

Pavement Design Methodologies

- Experience
  - *For example, local governments often specify city streets to be designed using a given cross section (e.g., 100 mm of HMA over 150 mm of crushed stone)*
  - *because they have found that this cross section has produced adequate pavements in the past.*

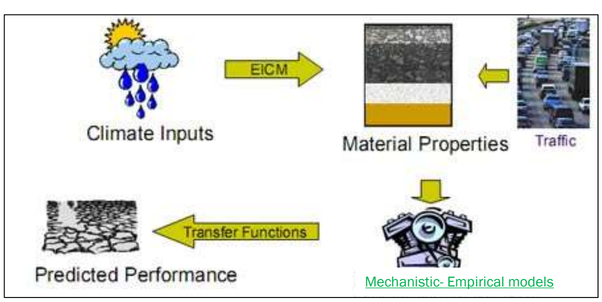


Pavement Design Methodologies

- Empirical
  - *Based on the results of experiments or experience*
    - e.g statistical models from road tests
  - *This means that the relationship between design inputs (e.g., loads, materials, layer configurations and environment) and pavement failure were arrived at through experience, experimentation or a combination of both.*
  - *For example*
    - California Bearing Ratio Method
    - American Association of State Highway and Transportation Officials (AASHTO 1993) Method

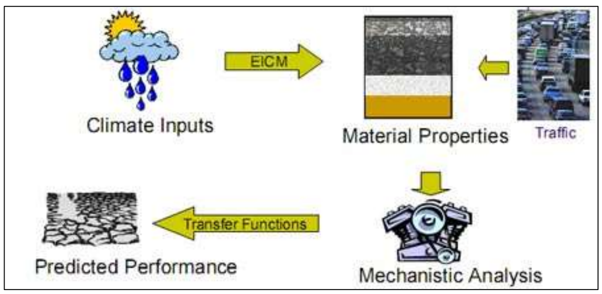
Pavement Design Methodologies

- Mechanistic- Empirical
  - *The phenomena are the stresses, strains and deflections within a pavement structure,*
  - *The physical causes are the loads and material properties of the pavement structure.*
  - *The relationship between these phenomena and their physical causes is typically described using a **Empirical -based mathematical model***
  - *For example*
    - AASHTO Mechanistic-Empirical pavement design (AASHTOWare Pavement ME Design)



Pavement Design Methodologies

- Mechanistic
  - *The phenomena are the stresses, strains and deflections within a pavement structure,*
  - *The physical causes are the loads and material properties of the pavement structure.*
  - *The relationship between these phenomena and their physical causes is typically described* ***using a*** **Mechanics-based** ***mathematical model***

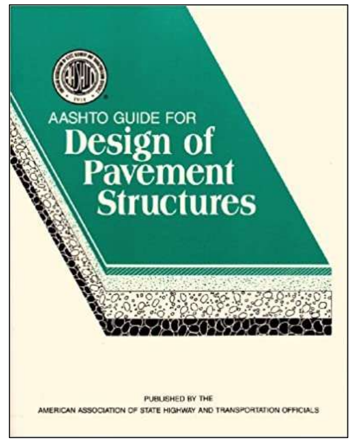


AASHTO 1993 Design Method

AASHTO 1993 Design Method

History

- The AASHO method for design of highway pavements is based primarily on the results of the AASHTO road test in late 1950's
- It was a cooperative effort carried out under the sponsor of 49 states
- The AASHO Road Test, a $27 million (1960 dollars) investment and the largest road experiment of its time
- The information obtained from the AASHO Road Test was crucial in advancing knowledge of
  - *Pavement structural design*
  - *Pavement performance*
  - *Load equivalencies*
  - *Climate effects*

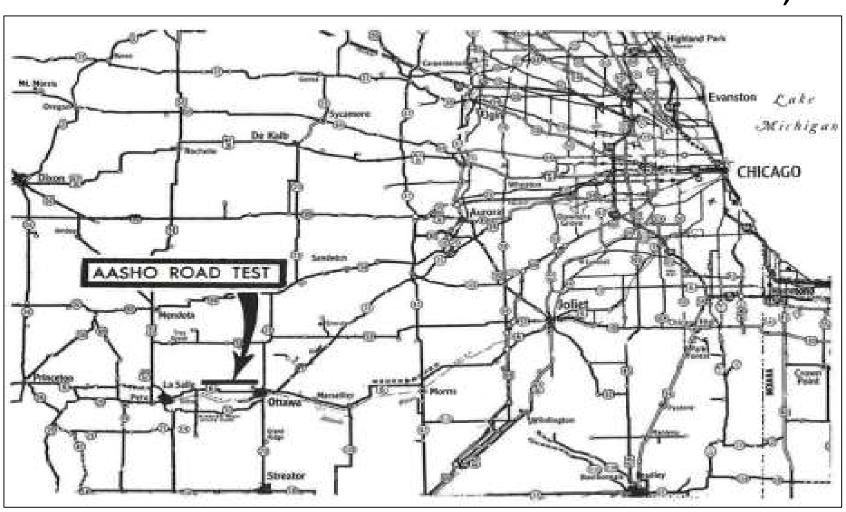


The AASHO Road Test: Report 1, History and Description of the Project. Special Report 61A. Highway Research Board, National Academy of Sciences. Washington, D.C

AASHO Road Test

Location

- The AASHO road test that was conducted in Ottawa, Illinois.



The AASHO Road Test: Report 1, History and Description of the Project. Special Report 61A. Highway Research Board, National Academy of Sciences. Washington, D.C

Test sections

- Tests were conducted on
  - *Short-span bridges*
  - *Flexible pavements Test sections*
  - *Rigid pavements Test sections*

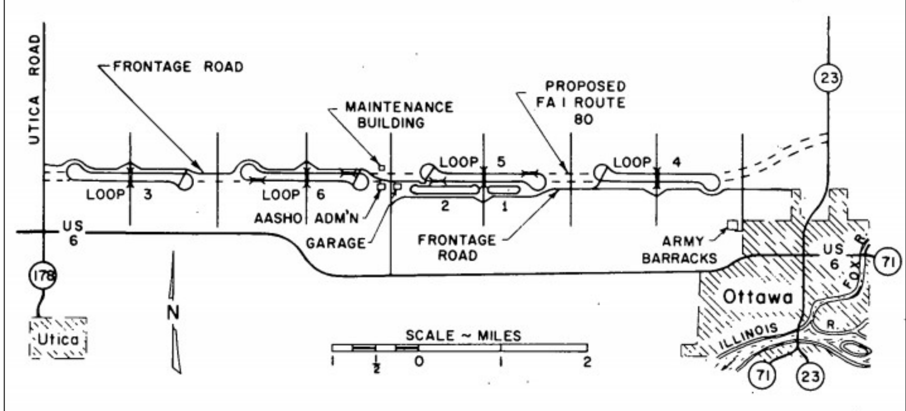
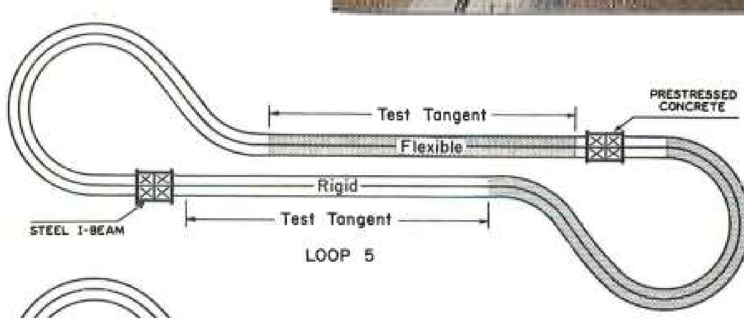


Figure 2. Layout of AASHO Road Test.

AASHO Road Test

Test sections

- The pavement test sections consisted of
  - *Two small loops*
  - *Four larger ones with each being a four-lane divided highway.*
- The tangent sections consisted of
  - *a successive set of pavement lengths of different designs, each length being at least 100 feet.*



The AASHO Road Test: Report 1, History and Description of the Project. Special Report 61A. Highway Research Board, National Academy of Sciences. Washington, D.C

AASHO Road Test

Test conditions

- One rainfall zone
- One temperature zone
- One subgrade (A-6/ A-7-6 [Clay])

AASHO Road Test

Materials

- One asphalt layer
  - *¾” surface course*
  - *1” binder course*
- One PCC layer
- Four base materials
  - *Main experiment*
    - Well-graded crushed limestone
  - *Special studies*
    - Well-graded uncrushed gravel
    - Bituminous-treated base (special studies)
    - Cement-treated base

AASHO Road Test

Truck Traffic

- Test traffic consisting of
  - *Single-axle vehicles*
    - Loads ranging from 2,000 to 30,000 pounds
  - *Tandem-axle vehicles*
    - Loads ranging from 24,000 to 48,000 pounds
- Traffic were driven over the test sections until several thousand load repetitions had been made.

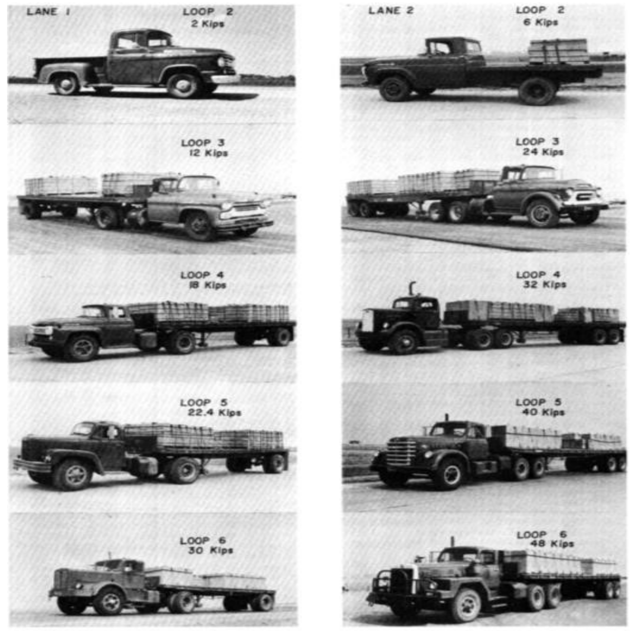


FIGURE 3 AASHO Road Test truck traffic.

AASHO Road Test

Truck Traffic

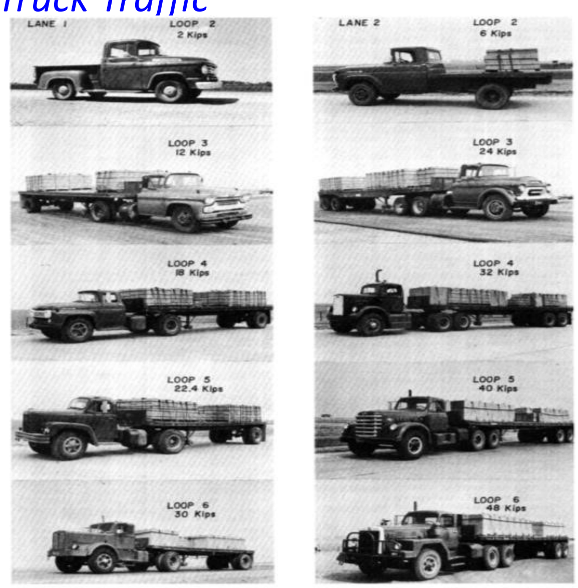


FIGURE 3 AASHO Road Test truck traffic.

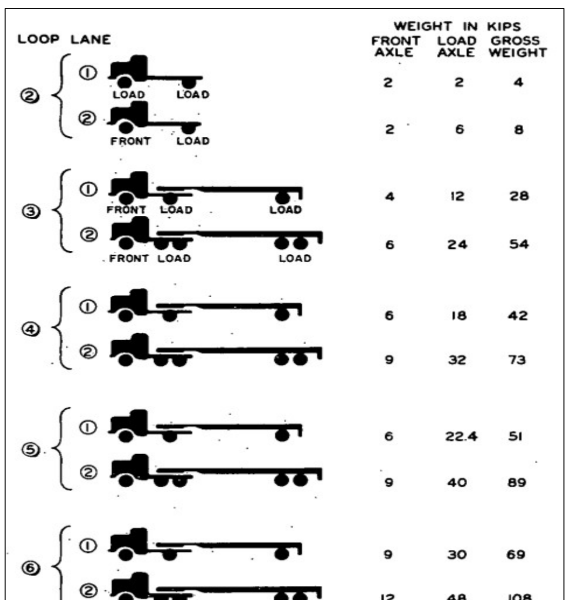


Figure 7. Typical test vehicle axle loadings.

AASHTO Pavement Design

Method Development

- 1961 (Interim Guide)
- 1972
- 1986
  - *Refined material characterization*
  - *Version included in Huang (1993)*
- 1993
  - *More on rehabilitation*
  - *More consistency between flexible, rigid designs*
- 2002
  - *Mechanistic-empirical approach (AASHTO ME)*

AASHTO 1993 Design Concept

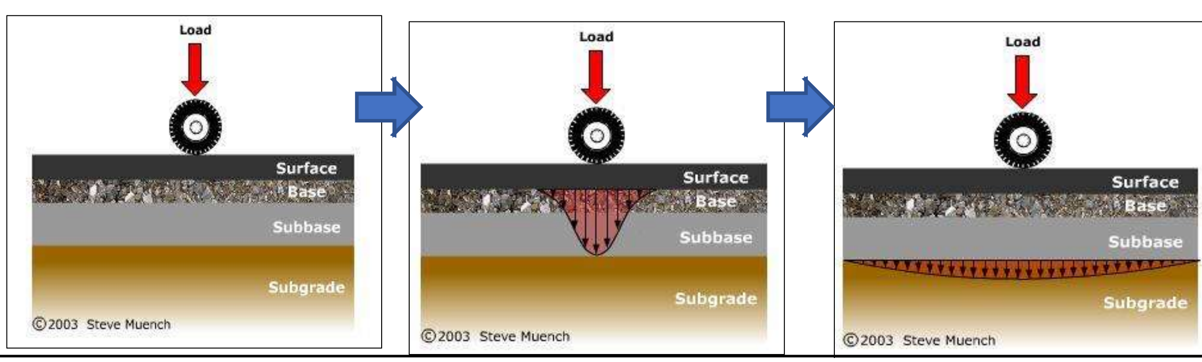
Design Concept

- The objective of the design using the AASHTO method is to determine
  - A *flexible pavement* *Structural Number (SN)* *adequate to carry the projected design traffic,* ***then*** *the determined SN is used to determine the required layer thickness*

Purpose of Pavement Systems

Load Support

- Distributes traffic loads to prevent damage to underlying soils and maintain structural integrity.

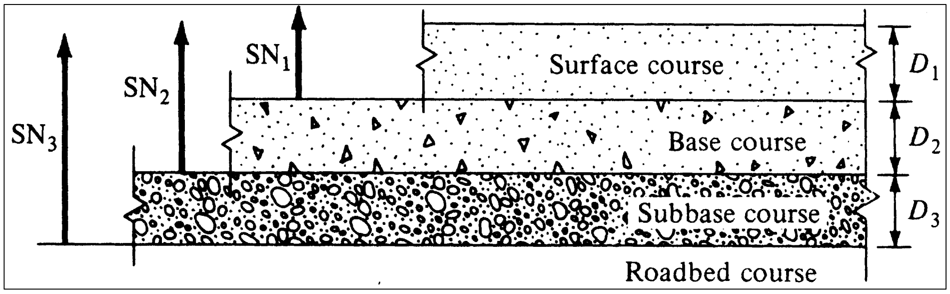


24

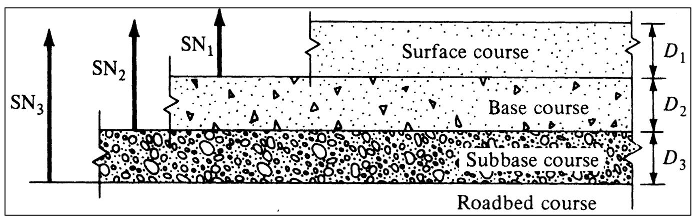
Structure Design

Structural Number (SN)

- 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*

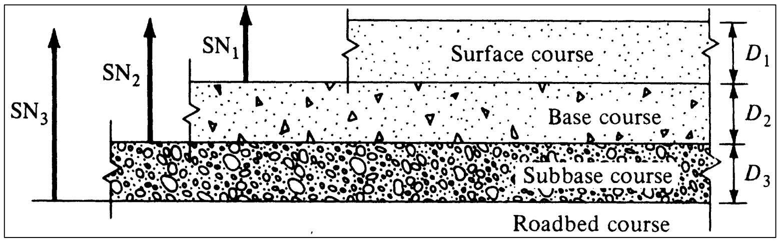


Relation between SN and layers thickness



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

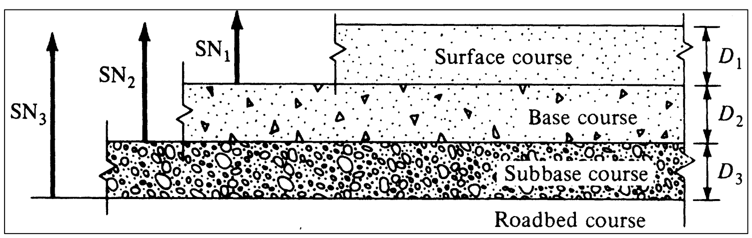
Relation between SN and layers thickness



- $D_2 \geq \frac{SN_2 - SN_1}{a_2 m_2}$

  - *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*

Relation between SN and layers thickness



- $D_3 \geq \frac{SN_3 - SN_2 - SN_1}{a_3 m_3}$

  - *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

Design Concept

- The objective of the design using the AASHTO method is to determine
  - *a flexible pavement Structural Number (SN) adequate to carry the projected design traffic, then the determined SN is used to determine the required layer thickness*

Design steps

■ *Step -1:*

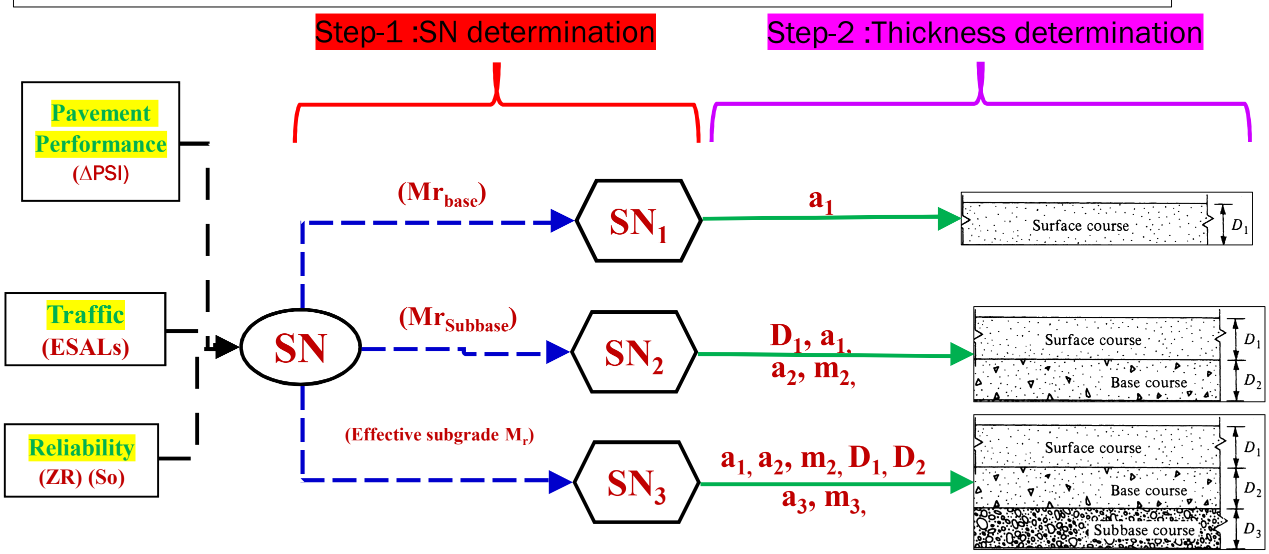
➢ *Determine the Structural Number (SN) for pavement layers*

- ❖ 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 -2 :*

➢ *Estimate the required layers thickness based on SNs values*

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



Step -1:
Determination of Pavement Layers Structural Numbers (SNs)

SN Determenation

Basic Design Equation

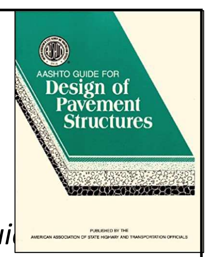
$$\log_{10}W_{18} = Z_R S_o + 9.36\log_{10}(\mathrm{SN}+1) - 0.20 + \frac{\log_{10}[\Delta\mathrm{PSI}/(4.2-1.5)]}{0.40 + [1094/(\mathrm{SN}+1)^{5.19}]} + 2.32\log_{10}M_r - 8.07 \quad (19.7)$$

- 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 = resilient modulus for Base, subbase, and effective subgrade layers lb/in^2

Design Inputs

AASHTO 1993 design method

Design Considerations



A. Design Variables:

- *Criteria considered for each type of road surface design procedure in the Gui*

B. Performance Criteria:

- *User-specified boundary conditions for pavement performance (e.g., serviceability).*

C. Material Properties for Structural Design:

- *Pavement and roadbed soil material properties required for structural design.*

D. Structural Characteristics:

- *Physical characteristics of the pavement structure affecting its performance.*

A. Design Variables

Performance Period

38

Design Variables

Performance Period

- **Definition:**
  - *The time a pavement structure lasts before needing rehabilitation.*
- **Key Considerations:**
  - ***Minimum Performance Period:***
    - Shortest time a pavement should last (e.g., 10 years before major rehabilitation).
    - Affected by public perception, funds, and engineering constraints.
  - ***Maximum Performance Period:***
    - Longest practical time a pavement is expected to last (e.g., 15-20 years).
    - Impacted by environmental factors, surface disintegration, and loss of serviceability.
- **Designer's Role:**
  - *Set realistic performance bounds based on experience, policy, and maintenance practices.*

A. Design Variables

Analysis Period

40

Design Variables

Analysis Period

- **Definition:**
  - *The time frame for which a design strategy is analyzed, analogous to "design life."*
- **Historical Context:**
  - *Traditionally, pavements were designed for a 20-year analysis period*
  - *Modern designs recommend longer analysis periods for better evaluation of long-term strategies and life-cycle costs.*
- **Key Recommendations:**

Highway Conditions	Analysis Period (years)
High-volume urban	30–50
High-volume rural	20–50
Low-volume paved	15–25
Low-volume aggregate surface	10–20

A. Design Variables

Traffic

42

Design Variables

Traffic

- **Key Basis:**
  - *Design procedures rely on cumulative* ***18-kip Equivalent Single Axle Loads (ESAL)*** *during the analysis period.*
- **Traffic Conversion:**
  - *Mixed traffic is converted into 18-kip ESAL units using equivalency values provided in the Guide .*
  - *Will be discussed later*
- **Analysis Period:**
  - *If no rehabilitation or resurfacing is planned, total traffic is calculated for the entire analysis period.*

A. Design Variables

Reliability

Reliability

- The AASHTO Definition of reliability is:
  - *"The reliability of the pavement design-performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period."*
- AASHTO uses the reliability concept to account ***for design uncertainties***.
- For example,
  - *A designer may specify that there should only be a 5 % chance that the design does not last a specified number of years (e.g., 20 years).*
  - *This is the same as stating that there should be a 95 % chance that the design does last the specified number of years (e.g., 20 years).*

Reliability

- The level of reliability to be used for design should increase with the increase of
  - The volume of traffic
  - Difficulty of diverting traffic
  - Public expectation of availability

Table 19.7 Suggested Levels of Reliability for Various Functional Classifications

	Recommended Level of Reliability	
Functional Classification	*Urban*	*Rural*
Interstate and other freeways	85–99.9	80–99.9
Other principal arterials	80–99	75–95
Collectors	80–95	75–95
Local	50–80	50–80

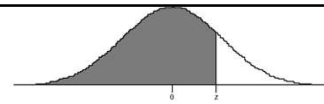
Reliability

- The reliability factor is comprised of two variable
  - Z_R = standard normal deviate
  - S_o = combined standard error of the traffic and performance prediction

Reliability

Z_R = standard normal deviate.

- The standard normal table value corresponding to a desired probability of exceedance level.



Normal Deviate z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-4.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-3.9	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-3.8	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-3.7	.0001	.0001	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-3.6	.0002	.0002	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.5	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002
-3.4	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
-3.3	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
-3.2	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
-3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
-3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
-2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
-2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
-2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
-2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
-2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
-2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
-2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
-2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
-2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
-2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
-1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
-1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
-1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
-1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
-1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
-1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
-1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
-1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
-1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
-1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
-.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
-.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
-.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
-.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
-.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
-.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
-.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483

Reliability

Recommended Values of Z_R

Standard Normal Deviation (Z_R) Values Corresponding to Selected Levels of Reliability

Reliability (R%)	*Standard Normal Deviation, Z_R*
50	−0.000
60	−0.253
70	−0.524
75	−0.674
80	−0.841
85	−1.037
90	−1.282
91	−1.340
92	−1.405
93	−1.476
94	−1.555
95	−1.645
96	−1.751
97	−1.881
98	−2.054
99	−2.327
99.9	−3.090
99.99	−3.750

Z_R = standard normal deviate.

Example 4

- For example,
  - *A designer may specify that there should only be a 5 % chance that the design does not last a specified number of years (e.g., 20 years).*
  - *This is the same as stating that there should be a 95 % chance that the design does last the specified number of years (e.g., 20 years).*
- Then,
  - *the reliability is 95 % (100 % – 5 %)*
  - *The corresponding Z_R value is -1.645*

Reliability (R%)	*Standard Normal Deviation, Z_R*
50	−0.000
60	−0.253
70	−0.524
75	−0.674
80	−0.841
85	−1.037
90	−1.282
91	−1.340
92	−1.405
93	−1.476
94	−1.555
95	−1.645
96	−1.751
97	−1.881
98	−2.054
99	−2.327
99.9	−3.090
99.99	−3.750

Reliability

S_o = Overall standard deviation of the traffic prediction and performance prediction

- This variable defines how widely the two basic design inputs, traffic and performance, can vary.
- For instance,
  - *Traffic may be estimated at 2,000,000 ESALs over 20 years.*
  - *However, actual traffic may turn out to be 2,500,000 ESALs over 20 years due to unanticipated population growth.*
  - *Similarly, pavement design factors may turn out to be different than estimated*
    - The more these values vary, the higher the value of S_o.

Reliability

Recommended Values of S_o

	Standard Deviation, S_o
Flexible pavements	0.40–0.50
Rigid pavements	0.30–0.40

The more these values vary, the higher the value of S_o.

Step to determine Reliability parameters

Steps

- **Functional Classification:**
  - *Define whether the facility is rural or urban.*
- **Reliability Level:**
  - *Select a reliability level based on Table 2.2.*
  - *Higher reliability requires more pavement structure.*
- **Standard Deviation (S_0):**
  - *Choose a value representative of local conditions.*
  - *AASHO Road Test values:*
    - **Rigid pavements:** S_0 = 0.35.
    - **Flexible pavements:** S_0 = 0.45.

Reliability Concept

Problem

You are designing a **principal arterial road** in a **rural area** with a **traffic loading** (W_{18}) **of 15 million ESALs** and a **reliability level of 95%**. Based on the **AASHO Road Tests**, determine the **reliability factor** (Z_R) and the **standard deviation** (S_0) for both **rigid** and **flexible pavements**.

Reliability Concept

Solution

1. **Find Z_R:**
    - From the standard normal table:
        - For $R = 95\%$, $Z_R = 1.645$.
2. **Use S_0 Values from AASHO Road Test:**
    - **Rigid Pavements:** $S_0 = 0.35$.
    - **Flexible Pavements:** $S_0 = 0.45$.

	Standard Deviation, S_o
Flexible pavements	0.40–0.50
Rigid pavements	0.30–0.40

Reliability (R%)	*Standard Normal Deviation, Z_R*
50	−0.000
60	−0.253
70	−0.524
75	−0.674
80	−0.841
85	−1.037
90	−1.282
91	−1.340
92	−1.405
93	−1.476
94	−1.555
95	−1.645
96	−1.751
97	−1.881
98	−2.054
99	−2.327
99.9	−3.090
99.99	−3.750

B. Performance Criteria

Serviceability

56

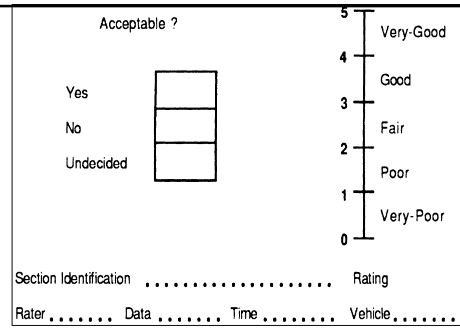
Pavement performance

Serviceability-Performance concept

- The *serviceability-performance* was developed to quantify pavement performance
- The serviceability of a pavement
  - *is defined as its ability to serve the type of traffic which use the facility*
- The serviceability is express in terms of the Present Serviceability Index (PSI)

Pavement performance

Present serviceability Index (PSI)



- The PSI is just a measure of the current overall rating of a section of highway based upon visual observation
- PSI ranges from
  - *5 = means excellent conditions*
  - *0 = essentially impassable*

PSI = 5

PSI = 0

Pavement performance

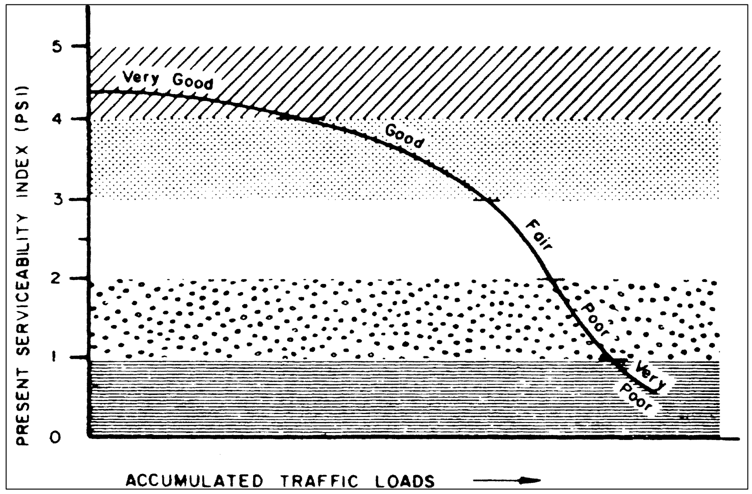
Serviceability-Performance concept

- The PSI is obtained from measurement of pavement
  - *Roughness*
    - [Reflect the functional performance]
  - *The extent & type distress*
    - Which were measured in terms of extent of cracking, patching, and rut depth for flexible pavements
    - [Reflect the structural performance]
- The evaluation is systematic but **subjective**

Pavement performance

Present serviceability Index (PSI) for design consideration

- Two serviceability indices are used in the design procedure:
  - *The initial serviceability index (P_i)*
    - is the serviceability index immediately after the construction of the pavement
    - AASHTO road test, a value of 4.2 was used for Pi for flexible pavements.
    - AASHTO recommends that each agency determine more reliable levels for pi based on existing conditions

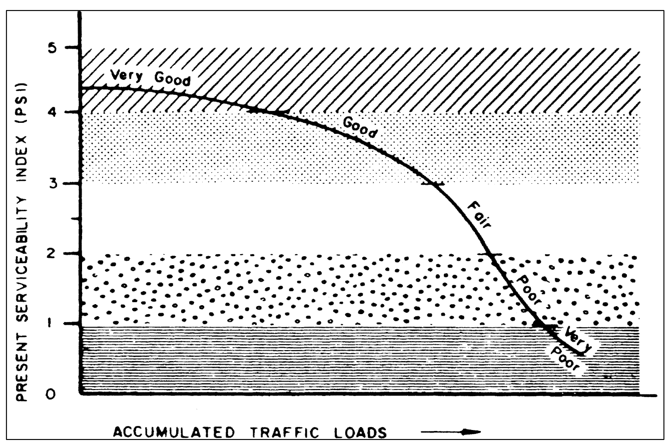


As the number of traffic loadings increases, the PSI declines

Pavement performance

Present serviceability Index (PSI) for design consideration

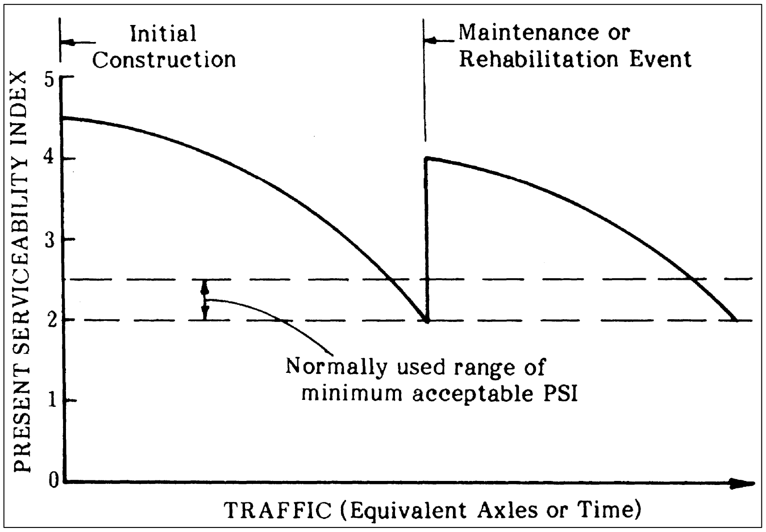
- Two serviceability indices are used in the design procedure:
  - The terminal serviceability index (P_t)
    - is the minimum acceptable value before resurfacing or reconstruction is necessary
    - Recommended values for the terminal serviceability index are
      - *2.5 or 3.0 for major highways*
      - *2.0 for highways with a lower classification.*
      - *1.5 In cases where economic constraints restrict capital expenditures for construction, or the performance period may be reduced*



As the number of traffic loadings increases, the PSI declines

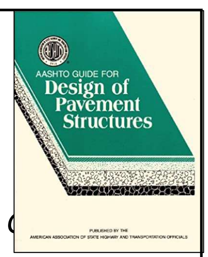
Pavement performance

Present serviceability Index (PSI)



After reaching the P_t, a maintenance/ rehabilitation is needed

AASHTO 1993 design method



Design Considerations

A. Design Variables:

- *Criteria considered for each type of road surface design procedure in the (*

B. Performance Criteria:

- *User-specified boundary conditions for pavement performance (e.g., serviceability).*

C. Material Properties for Structural Design:

- *Pavement and roadbed soil material properties required for structural design.*

D. Structural Characteristics:

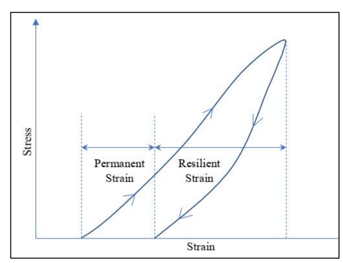
- *Physical characteristics of the pavement structure affecting its performance.*

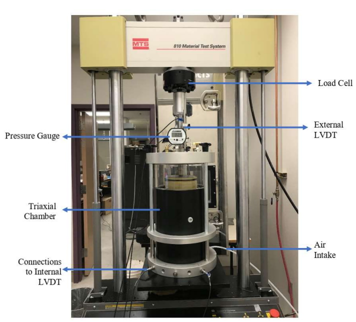
C. Material Properties for Structural Design

Effective Roadbed Soil Resilient Modulus

Roadbed Soils (Subgrade Material)

- The 1993 AASHTO guide uses the resilient modulus (M_r) of the soil to define its property.
-





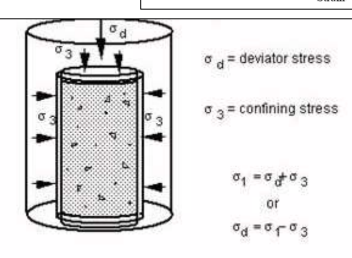


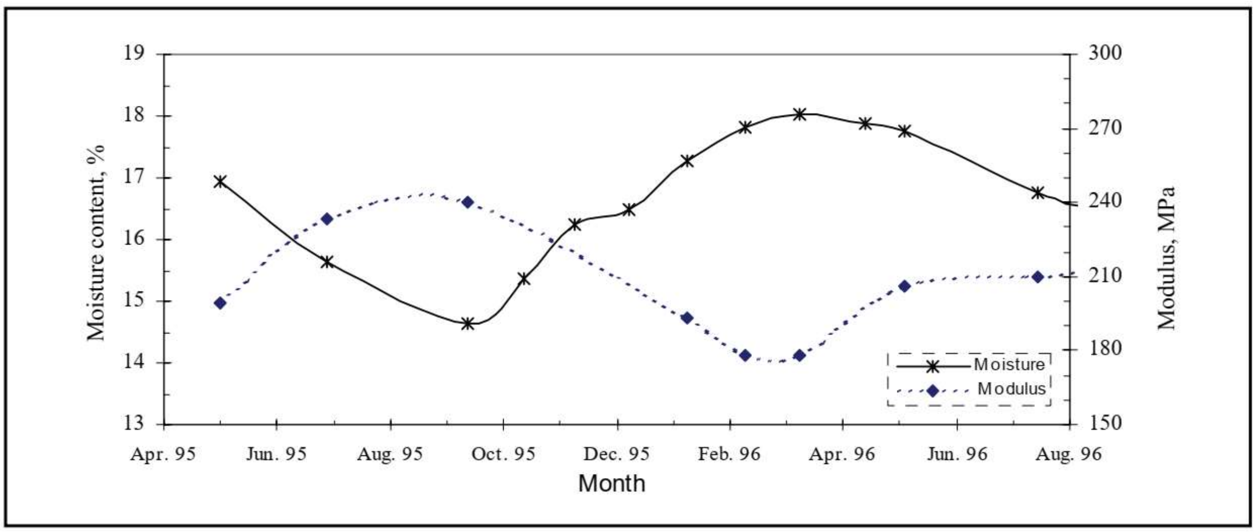
Figure 2a: Stresses Acting on Triaxial Specimen

Factors Affecting Resilient Modulus (Mr) of Subgrade Soils

- **Moisture Content**:
  - *Increased moisture leads to reduced stiffness and Mr*
- **Freeze-Thaw Cycles**:
  - *Mr can reduce by 50–80% during thaw periods due to frost action.*
- **Stress Levels**:
  - *High stress reduces soil elasticity, affecting Mr values*

Roadbed Soils (Subgrade Material)

Moisture content effects on Mr

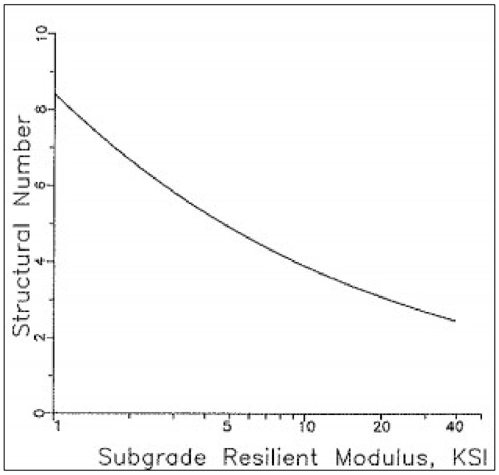


Moisture content and elastic modulus versus season for silty soil, site 24-1634

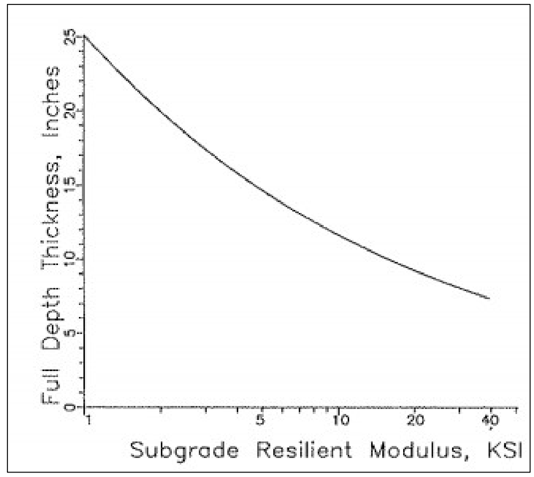
Hassan M. Salem, Effect Of Seasonal Moisture Variation On Subgrade Resilient Modulus, Improving Pavements With Long-Term Pavement Performance: Products for Today and Tomorrow,2005, https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/03049/paper4.cfm

Roadbed Soils (Subgrade Material)

Effects of Mr on AASHTO 1993 Design



Effect of subgrade resilient modulus on design structural number

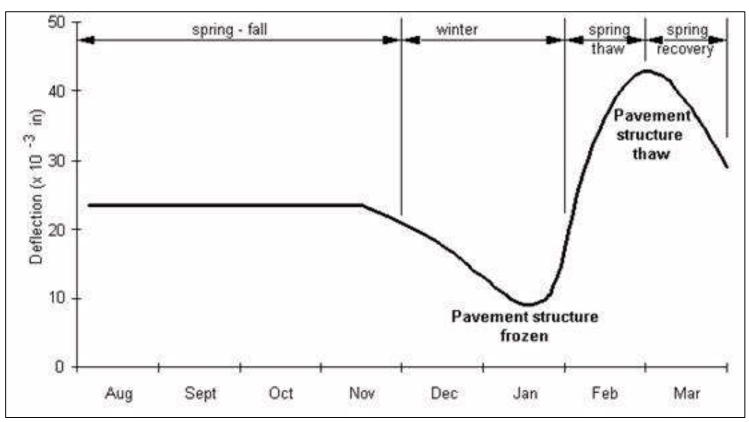


Effect of subgrade resilient modulus on design thickness

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Frost Action in Soils

- During winter
  - *Frost Heave : Distortion or expansion of the subgrade soil or base during freezing temperatures.*
  - *An upward movement of the subgrade resulting from the expansion of accumulated soil moisture as it freezes.*
- During spring
  - *(thawing) ice lenses melt which result in water content increase which in turns reducing the strength of the soil causing structural damage (spring break-up).*



Roadbed Soils (Subgrade Material)

Mr seasonal variation

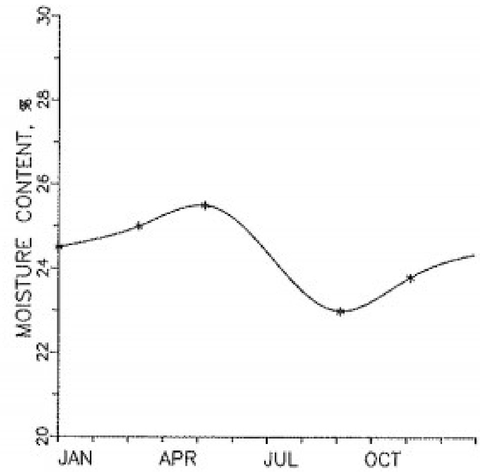


FIGURE 13 Seasonal moisture variation used in example.

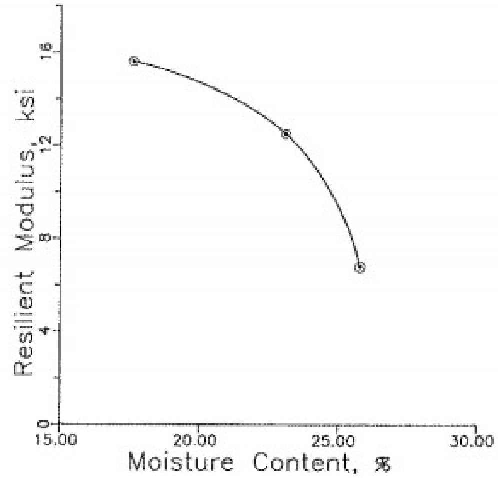


FIGURE 12 Moisture content-resilient modulus relationship for soil used in example.

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Roadbed Soils (Subgrade Material)

Mr Seasonal Variation

- Since the seasonal variation of resilient modulus is **quite complex**
  - *The selection of a* ***single*** *resilient modulus value for use in design can be quite complex.*
- Therefore, The object is
  - ***a single value*** *that is representative of the entire year has bee selected*
    - ***Called Effective Roadbed Soil Resilient Modulus***

Roadbed Soils (Subgrade Material)

Steps to determination of Effective Roadbed Soil Resilient Modulus

- **Step 1:**
  - *Develop a laboratory relationship between*
    - Resilient modulus
    - Subgrade moisture content
  - *For example :*
    - at 25% moisture content, Mr is 9500 Psi

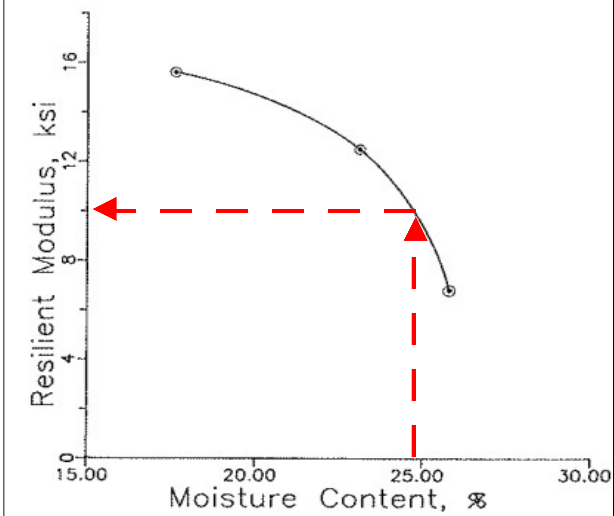


FIGURE 12 Moisture content-resilient modulus relationship for soil used in example.

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPORTATION RESEARCH RECORD, 1989

Roadbed Soils (Subgrade Material)

Determination of Effective Roadbed Soil Resilient Modulus

- **Step 2:**
  - *Estimate the seasonal variation in moisture content.*
    - There is no standard approach for making this estimate
  - A practical approach might be to sample a similar subgrade.
    - For this example it is assumed that moisture contents were determined four times during the year on a similar subgrade soil from a nearby pavement
    - For example:
      - *in March the water content was 25%*

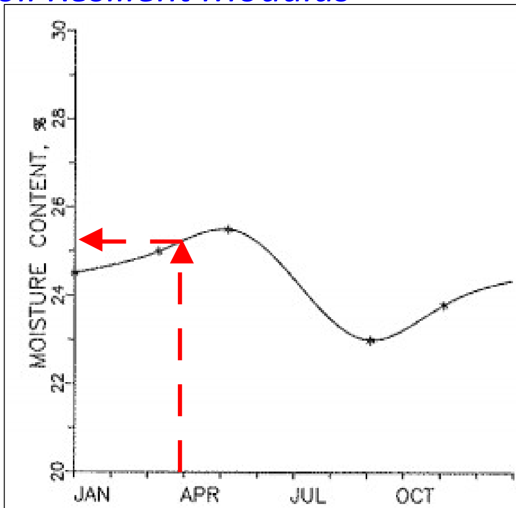


FIGURE 13 Seasonal moisture variation used in example.

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Roadbed Soils (Subgrade Material)

Determination of Effective Roadbed Soil Resilient Modulus

- **Step 3:**
  - *Determine the monthly (or bimonthly) resilient modulus*
    - Use data collected in step 1 and step 2
    - For example:
      - *March has water content of 25 % (step 2), which is correspond to 9,500 Mr (step 1)*

Month	Roadbed Soil Modulus, M_R (psi)
Jan.	30,000
Feb.	5,500
Mar.	9,500
Apr.	8,900
May	8,600
June	11,000
July	12,700
Aug.	13,000
Sept.	13,100
Oct.	12,800
Nov.	12,700
Dec.	12,300

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Roadbed Soils (Subgrade Material)

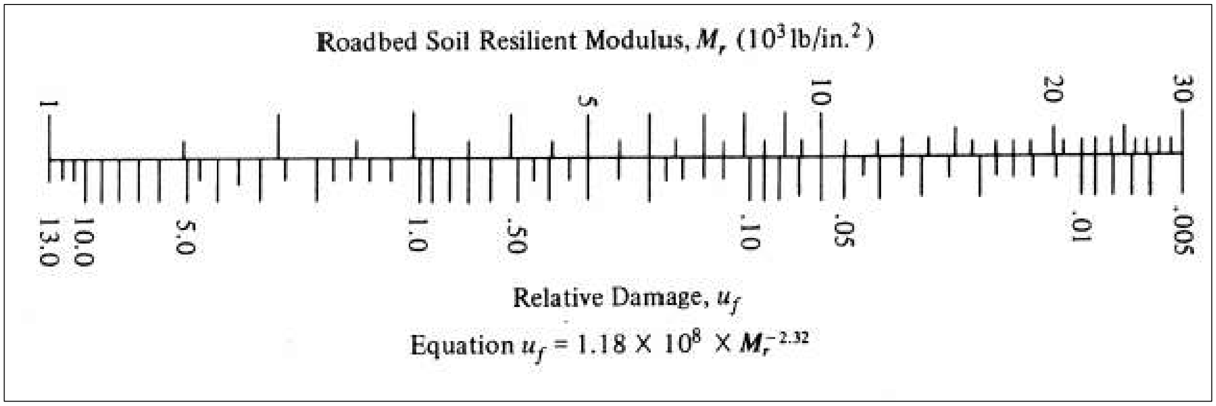
Determination of Effective Roadbed Soil Resilient Modulus

- **Step 4:**
  - *Determine the relative damage factor for each resilient modulus (U_f)*
  - $U_f = 1.18 \times 10^8 \times Mr^{-2.32}$
  - *For the frozen subgrade (January),*
    - The resilient modulus would be high resulting in a low relative damage
      - For practical purposes, a damage value of 0.0 is assigned

Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Roadbed Soils (Subgrade Material)

Determination of Effective Roadbed Soil Resilient Modulus



Roadbed Soils (Subgrade Material)

Determination of Effective Roadbed Soil Resilient Modulus

- **Step 5:**
  - ➢*Determine the average U_f for all months*
- $\overline{U_f} = \frac{\sum_{i=1}^{N} U_f}{n}$
  - ➢*n is number of months (12)*

Month	Roadbed Soil Modulus, M_R (psi)	Relative Damage, u_f
Jan.	30,000	.005
Feb.	5,500	.25
Mar.	9,500	.070
Apr.	8,900	.081
May	8,600	.088
June	11,000	.050
July	12,700	.038
Aug.	13,000	.034
Sept.	13,100	.033
Oct.	12,800	.035
Nov.	12,700	.036
Dec.	12,300	.038
Summation: Σu_f =		.758

$$\overline{U_f} = \frac{0.758}{12} = 0.063$$

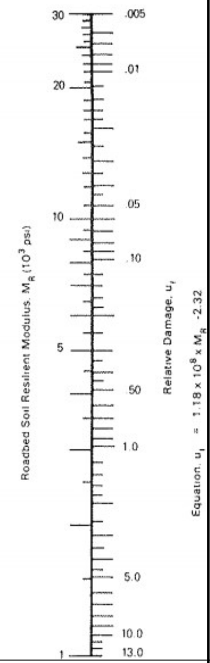
Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPORTATION RESEARCH RECORD, 1989

Roadbed Soils (Subgrade Material)

Determination of Effective Roadbed Soil

- **Step 6.**
  - *Determine the effective Mr using average* $\overline{U_f}$
  - Effective $Mr = 10^{\left[\frac{\log\left[\frac{\overline{U_f}}{1.18\times10^{8}}\right]}{-2.32}\right]}$
  - *For example:*
    - at $\overline{U_f}$ of 0.063 …. Effective Mr =9,900 Psi

Month	Roadbed Soil Modulus, M_R (psi)	Relative Damage, u_f
Jan.	30,000	.005
Feb.	5,500	.25
Mar.	9,500	.070
Apr.	8,900	.081
May	8,600	.088
June	11,000	.050
July	12,700	.038
Aug.	13,000	.034
Sept.	13,100	.033
Oct.	12,800	.035
Nov.	12,700	.036
Dec.	12,300	.038
Summation: Σu_f =		.758



Elliott,R and Thornton. S," Resilient Modulus and AASHTO Pavement Design, .TRANSPOR'TATION RESEARCH RECORD, 1989

Example 3

- The table show the roadbed soil resilient modulus *Mr* for each month estimated from laboratory results correlating *Mr* with moisture content.
- Determine
  - The effective resilient modulus of the subgrade

Month	Roadbed (Mr) (ib / in)
January	22000
February	22000
March	5500
April	5000
May	5000
June	8000
July	8000
August	8000
September	8500
October	8500
November	6000
December	22000

Example 3

Solution

Month	Roadbed (Mr) (ib / in)	Relative damage (U_f)
January	22000	0.010
February	22000	0.010
March	5500	0.248
April	5000	0.309
May	5000	0.309
June	8000	0.104
July	8000	0.104
August	8000	0.104
September	8500	0.090
October	8500	0.090
November	6000	0.203
December	22000	0.010

Summation of relative damage	1.591
Average U_f	0.133
Effective Mr	7203

C. Material Properties for Structural Design

Layer Coefficients concept

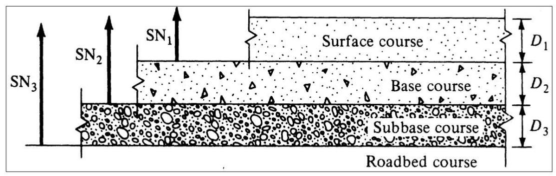
Layer Coefficients concept

- Definition:
  - *Numerical values (a_i) assigned to each layer material in the pavement structure.*
  - *Converts actual layer thickness into the* ***structural number*** *(SN) for flexible pavement design.*
- Purpose:
  - *Measures the* ***relative ability*** *of each layer to function as a structural component of the pavement.*

Structure Design

Structural Number (SN)

- 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*



Layer Coefficients concept

Layer Coefficients in the AASHTO Design Equation

- **AASHTO Structural Number Equation:**

$$SN = \sum(a_i \cdot D_i \cdot m_i)$$

  - a_i: Layer coefficient for material i.
  - D_i: Layer thickness (inches).
  - m_i: Drainage coefficient.

Layer Coefficients concept

Examples of Layer Coefficients

- Layer coefficients are Derived from Material Properties (Resilient Modulus)
- Materials with high stiffness, like asphalt concrete, have higher coefficients compared to granular layers.
- Example
  - *Asphalt Concrete (AC): 0.40–0.44*
  - *Granular Base: 0.11–0.14*
  - *Granular Subbase: 0.05–0.10*

Layer Coefficients concept

Factors Affecting Layer Coefficients

- Material Type:
  - *Asphalt, granular base, stabilized soil, etc.*
- Environmental Factors:
  - *Moisture levels*
  - *Drainage quality*

C. Material Properties for Structural Design

Layer Coefficients for

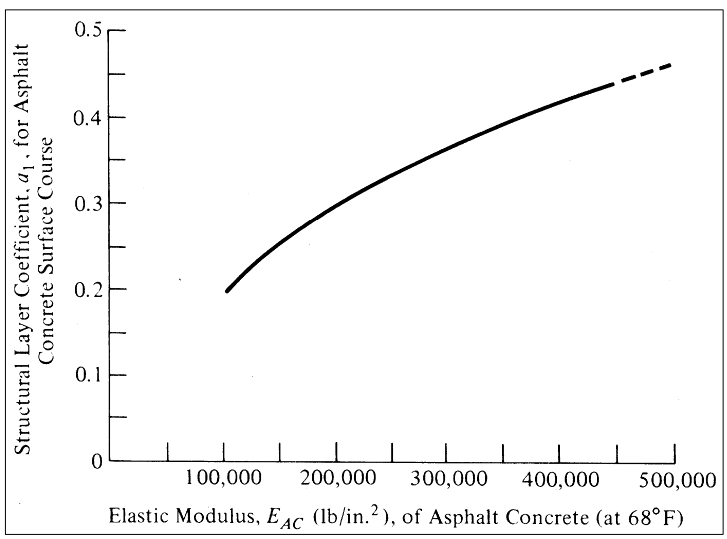
Asphalt Concrete Surface Course

90

Asphalt Concrete Surface Course

Layer Coefficient

- Figure provides a chart that may be used to estimate the structural layer coefficient of a dense-graded asphalt concrete surface course based on its elastic (resilient) modulus (E_{AC}) at 68°F.
- **Caution is** Recommended for modulus values above 450,000 psi.
- **Note:**
  - *Higher modulus asphalt concretes are **stiffer** and more **resistant to bending**.*
  - *However, they are also more **susceptible to thermal and fatigue cracking**.*



C. Material Properties for Structural Design

Layer Coefficients for

Granular Base Layers

92

Granular Base Layers

Layer Coefficient

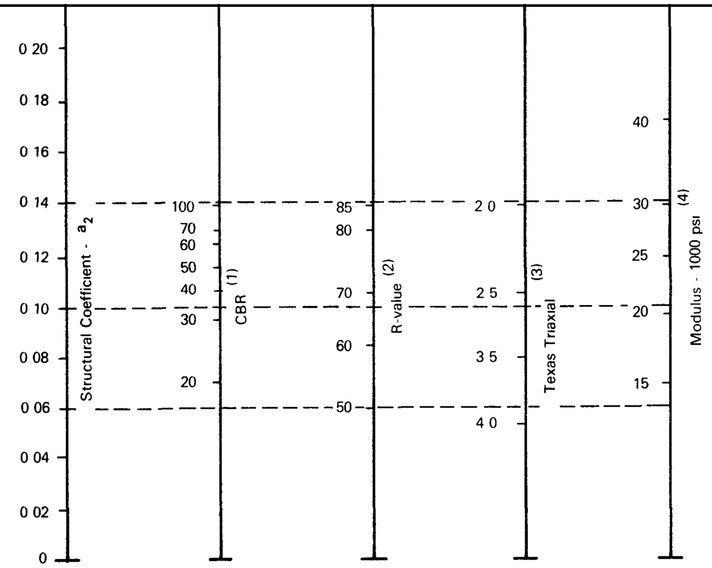
- **Quality of the Base**
  - *Determined in terms of the **layer coefficient (a2)**.*
- **Definition of a_2:**
  - *measures the **relative effectiveness** of the subbase material as a structural component of the pavement.*
  - *Converts the **actual thickness** of the base into an **equivalent Structural Number (SN)**.*
  - *Reflects the **strength contribution** of the material in pavement design.*
- **How to get a_2**
  - *Figure 2.6 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 base coefficient (a_2)

Untreated base

Variation in Granular base Layer Coefficient, a_2, with Various Subbase Strength Parameters

Higher a_2 coefficient indicate better base materials



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

Figure 2.6. Variation in Granular Base Layer Coefficient (a_2) with Various Base Strength Parameters *(3)*

C. Material Properties for Structural Design

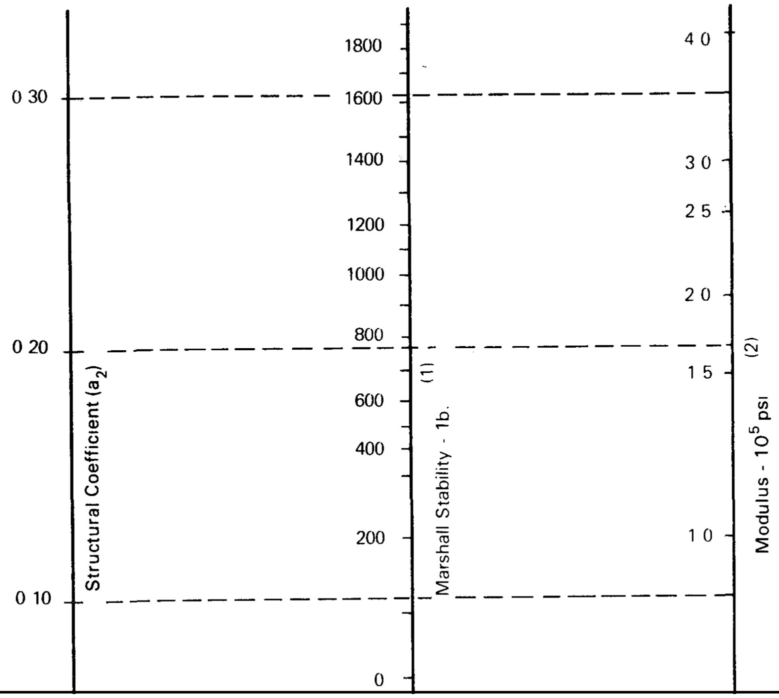
Layer Coefficients for

Treated Base Layers

Determination of base coefficient (a_2)

Higher a_2 coefficient indicate better base materials

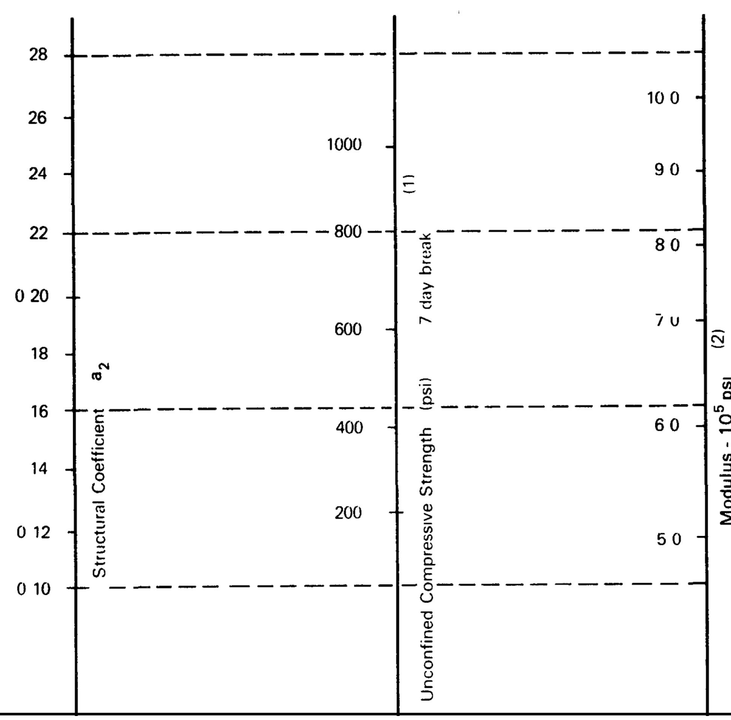
Bituminous-Treated base



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

Granular Base Layers

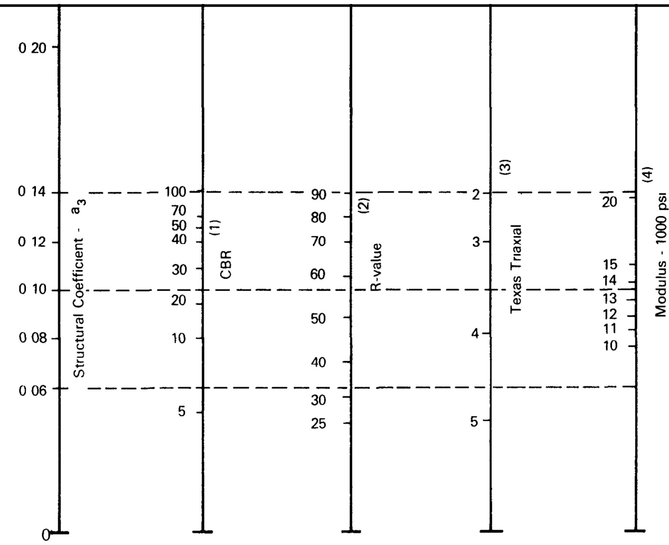
Layer Coefficient

- **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*)