Outline: Chapter 7

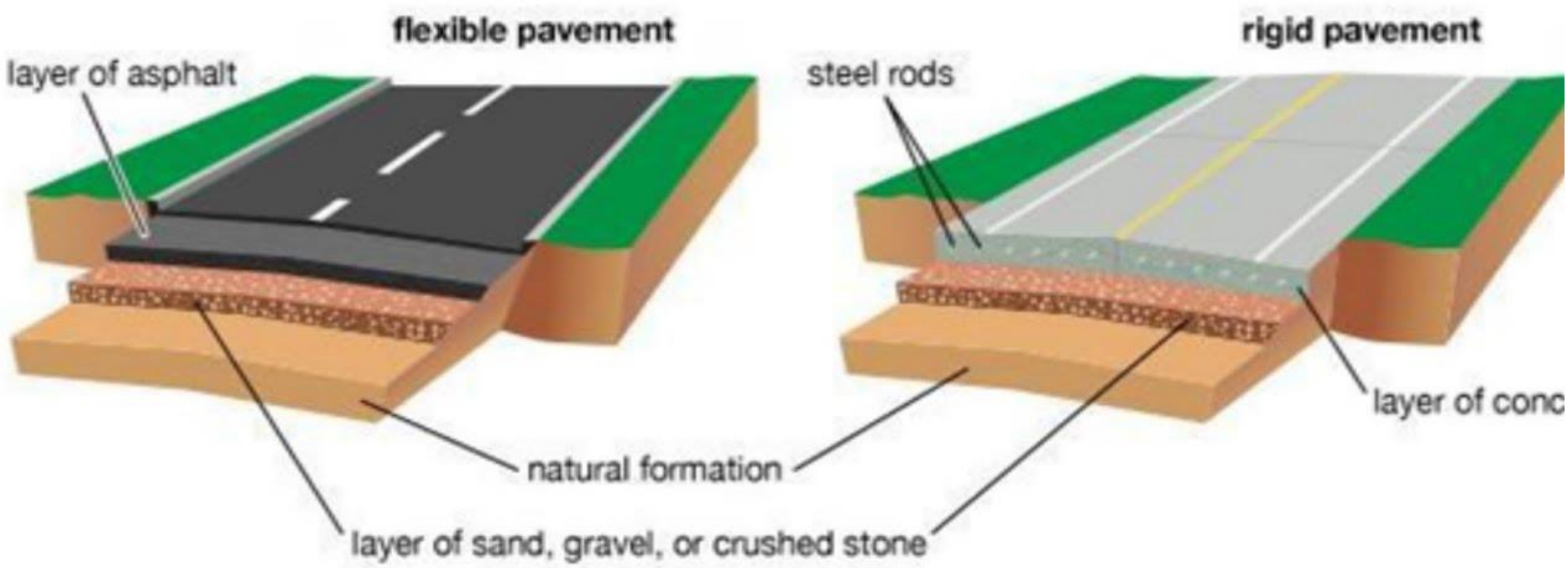
7.1 Flexible Pavement Design

7.2 Rigid Pavement Design

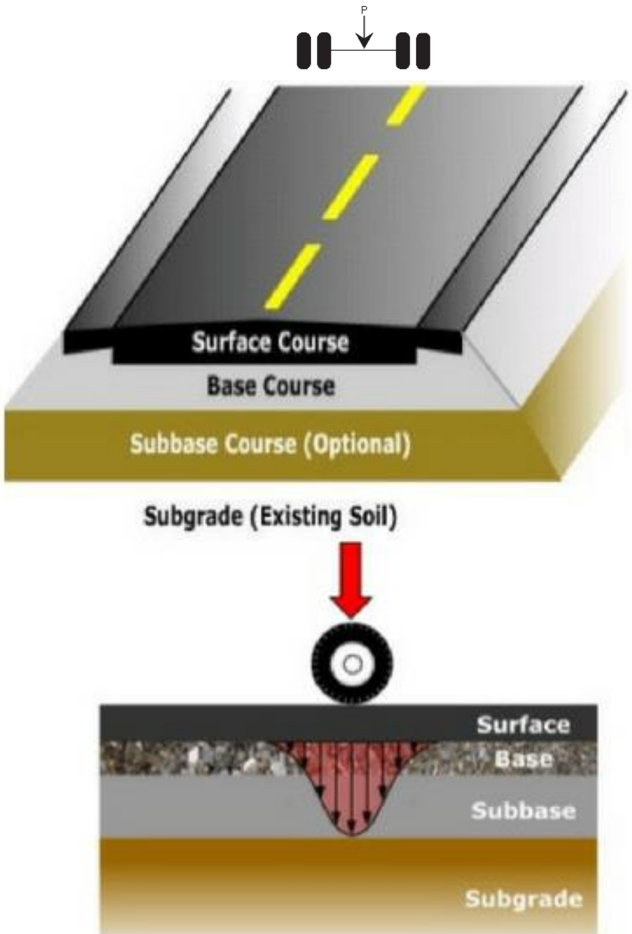
Highway Pavement

- Highway pavements are divided into two main categories:
  - **Flexible -**Bituminous concrete-
  - **Rigid -**Portland cement concrete-
- Flexible pavements usually consist of a bituminous surface underlaid with
  - a layer of granular material and
  - a layer of a suitable mixture of coarse and fine materials.

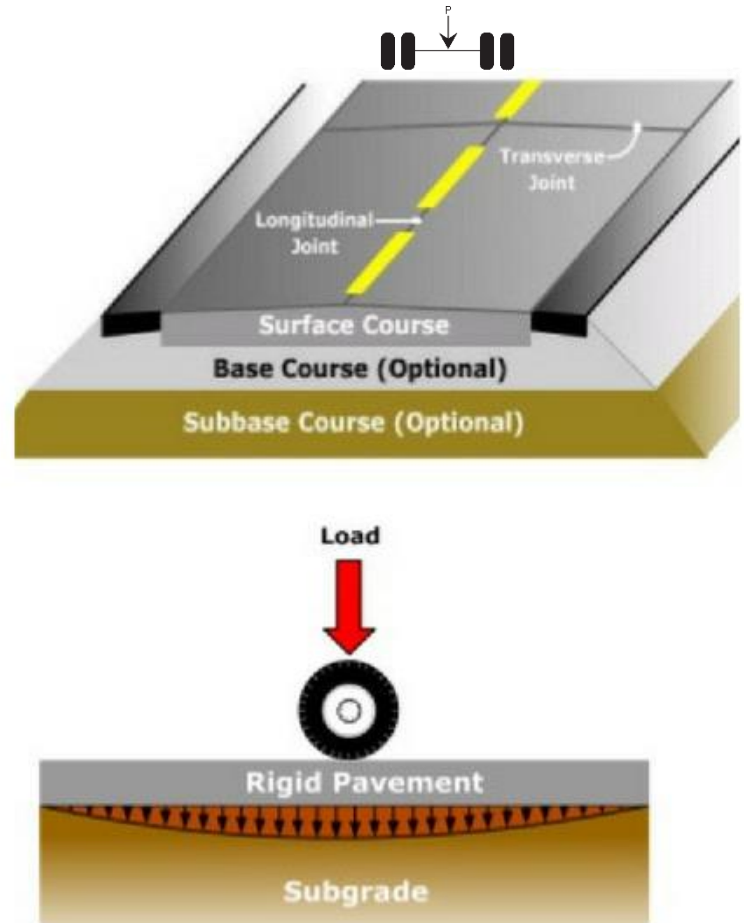
Difference between flexible and Rigid Pavement



Highway Pavement



Flexible



Rigid

Flexible Pavement

- Traffic loads are transferred by the wearing surface to the underlying supporting materials through:
  - Interlocking of aggregates
  - Frictional effect of granular materials
  - Cohesion of fine materials
- **Flexible pavements are divided into:**
  - **High-type pavements**
    - » They have wearing surfaces that adequately support the expected traffic load
    - » without visible distress due to fatigue and are not susceptible to weather conditions.

Flexible Pavement

- **Intermediate-type pavements**
  - » They have wearing surface that range from surface treated to those within qualities just below that of the high-type pavements.
- **Low-type pavements**
  - » They are used mainly for low-cost roads
  - » They have wearing surface that range from untreated to loose natural materials to surface-treated earth.

Flexible Pavement

- **The components of a flexible pavement:**

1. **Subgrade** (Prepared Road Bed)
   - It is usually the natural material located along the horizontal alignment of the pavement and serves as the foundation of the pavement structure.
   - It may be necessary to treat the subgrade material to achieve certain strength properties.

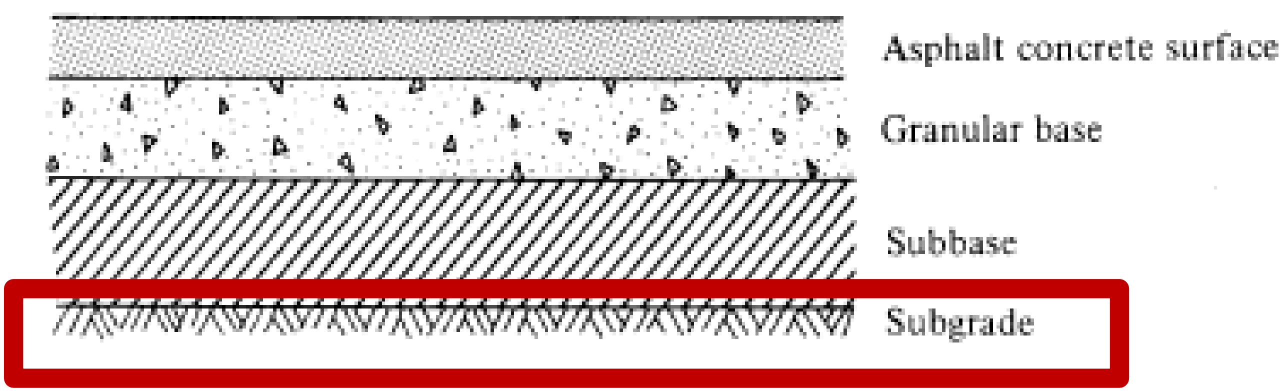


Figure 19.1 Schematic of a Flexible Pavement

Flexible Pavement

- **The components of a flexible pavement:**

2. Subbase Course
   - It consists of material of a superior quality to that which is generally used for subgrade construction
   - The requirements usually are given in terms of the **gradation, plastic characteristics, and strength**
   - Subbase may be omitted if it can be replaced by subgrade
   - Soil Stabilization can be used

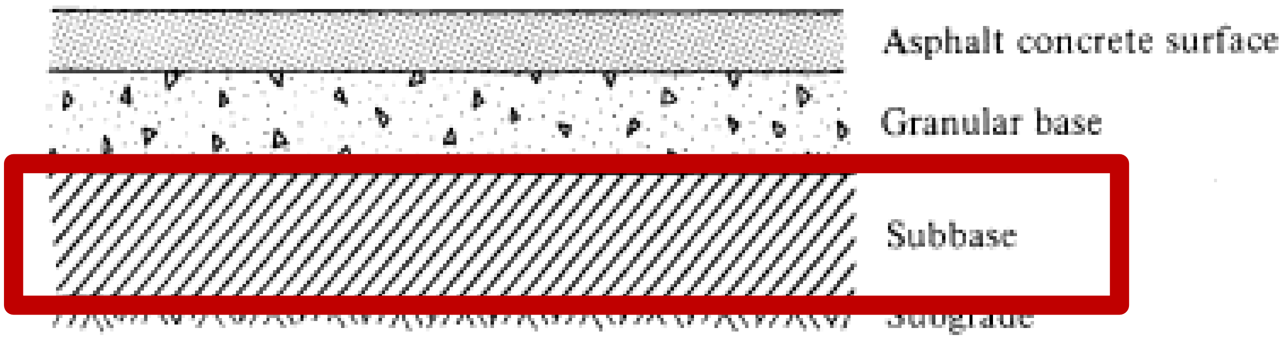


Figure 19.1 Schematic of a Flexible Pavement

Flexible Pavement

- **The components of a flexible pavement:**

3. **Base Course**
   - It consists of granular materials such as crushed stone, crushed or uncrushed slag, crushed or uncrushed gravel, and sand
   - Higher specification compared to subbase
   - May be stabilized using Portland cement, asphalt or lime, if available material don't meet the requirements

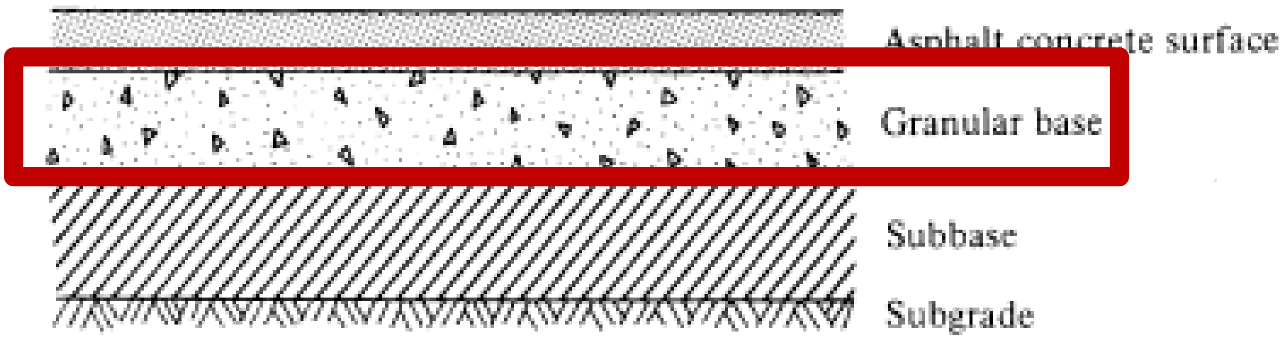


Figure 19.1 Schematic of a Flexible Pavement

Flexible Pavement

- **The components of a flexible pavement:**

4. **Surface Course**
   - A mixture of mineral aggregates and asphalt
   - It should be capable of:
     - » Withstanding high tire pressures,
     - » Resisting abrasive forces due to traffic,
     - » Providing a skid resistant driving surface,
     - » Preventing water penetration

The thickness varies from 5 cm to more than 15 cm

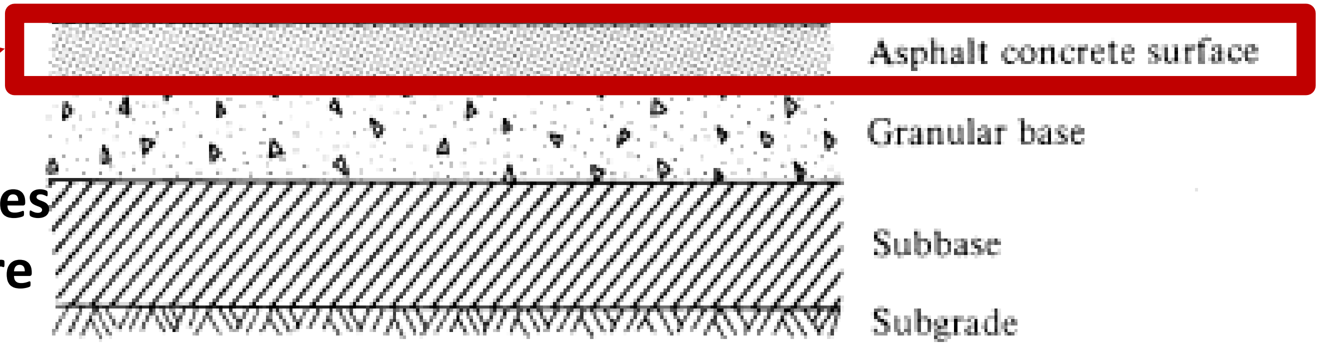


Figure 19.1 Schematic of a Flexible Pavement

Soil Stabilization

- It is the treatment of natural soil to improve its engineering properties.
- It can be divided into two categories:
  - **Mechanical:** is the blending of different grades of soils to obtain a required grade.
  - **Chemical:** is the blending of the natural soil with chemical agents. Three main types:
    - » **Cement Stabilization**
    - » **Asphalt Stabilization**
    - » **Lime Stabilization**

Cement Stabilization

- It involves the addition of 5 to 14 percent Portland cement by volume of the compacted mixture to the soil being stabilized
- Mainly to obtain improved soil, but also sometimes for base course materials
- Almost all types of soil can be stabilized with cement

Cement Stabilization

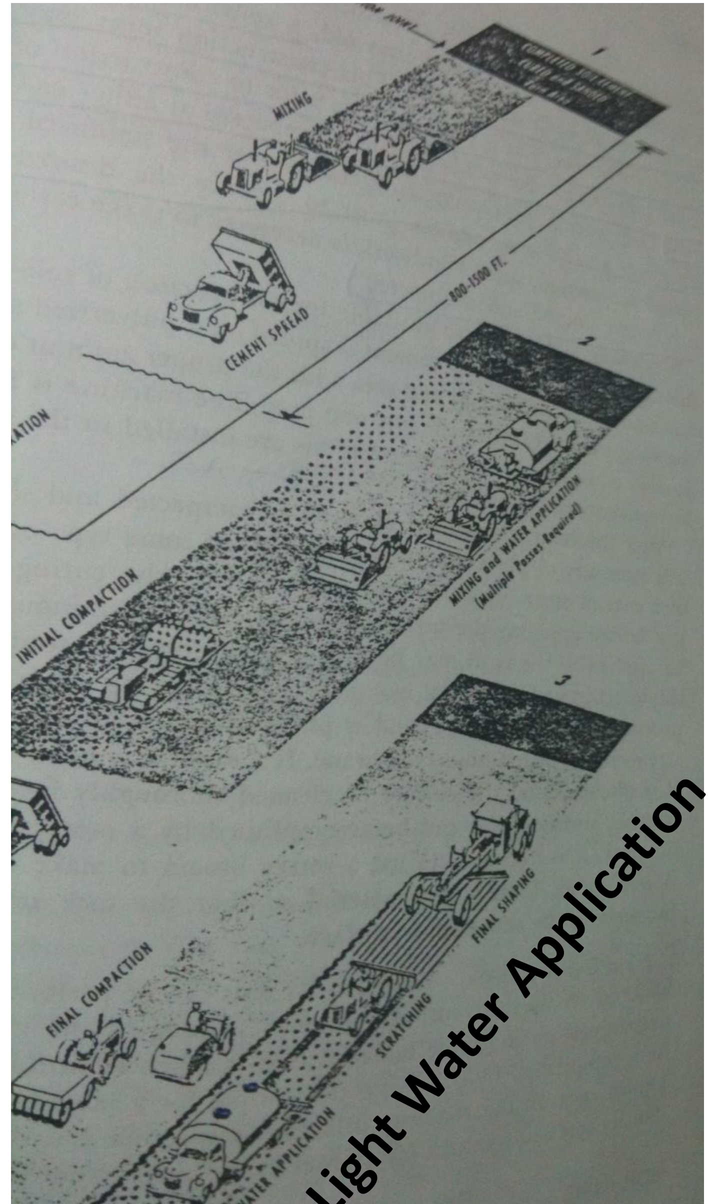
- Procedure for cement stabilization:
  - Pulverizing the soil
  - Mixing the required quantity of cement with the pulverized soil
  - Adding water and compacting the soil cement mixture (footsheep)
  - Curing the compacted layer

Cement Stabilization

Preparation

Cement Spread

Final Compaction



Light Water Application

Asphalt Stabilization

- Asphalt stabilization is to achieve one or both of the following:
  a. **Waterproofing of natural materials**
     - » It provides a membrane that impedes the penetration of water, thereby reducing the effect of any surface water that may enter the soil.
     - » In addition, surface water is prevented from seeping into the subgrade,
       - which protects the subgrade from failing due to increase in moisture content.

Asphalt Stabilization

- Asphalt stabilization is to achieve one or both of the following:

  b. Binding of natural materials

  » It improves the durability of the natural soil by providing an adhesive characteristic, increasing cohesion.

- % of Asphalt for stabilization can range from 3%-9%

Asphalt Stabilization

- **Requirements for soil to be stabilized by asphalt:**
  - **Less than 25 percent of the material passes the No. 200 sieve.**
    - » Smaller soil particles have large surface areas per unit volume which require a large amount of bituminous material for the soil surfaces to be adequately coated.
  - **A plasticity index (PI) less than 10,**
    - » Difficulty may be encountered in mixing soils with a high PI, which may result in the plastic fines swelling and thereby loosing strength.

Lime Stabilization

- It is one of the oldest processes of improving the engineering properties of soils
- Used for base and subbase materials
- Most commonly used materials are calcium hydroxide Ca(OH)2 and dolomite Ca(OH)2+MgO.
- Clayey materials are most suitable for lime stabilization
  - PI values less than 10
- Most fine-grained soil can be stabilized with **3 to 10% lime**, based on the dry weight of the soil

7.1 Flexible Pavement Design

General Principles of Flexible Pavement Design

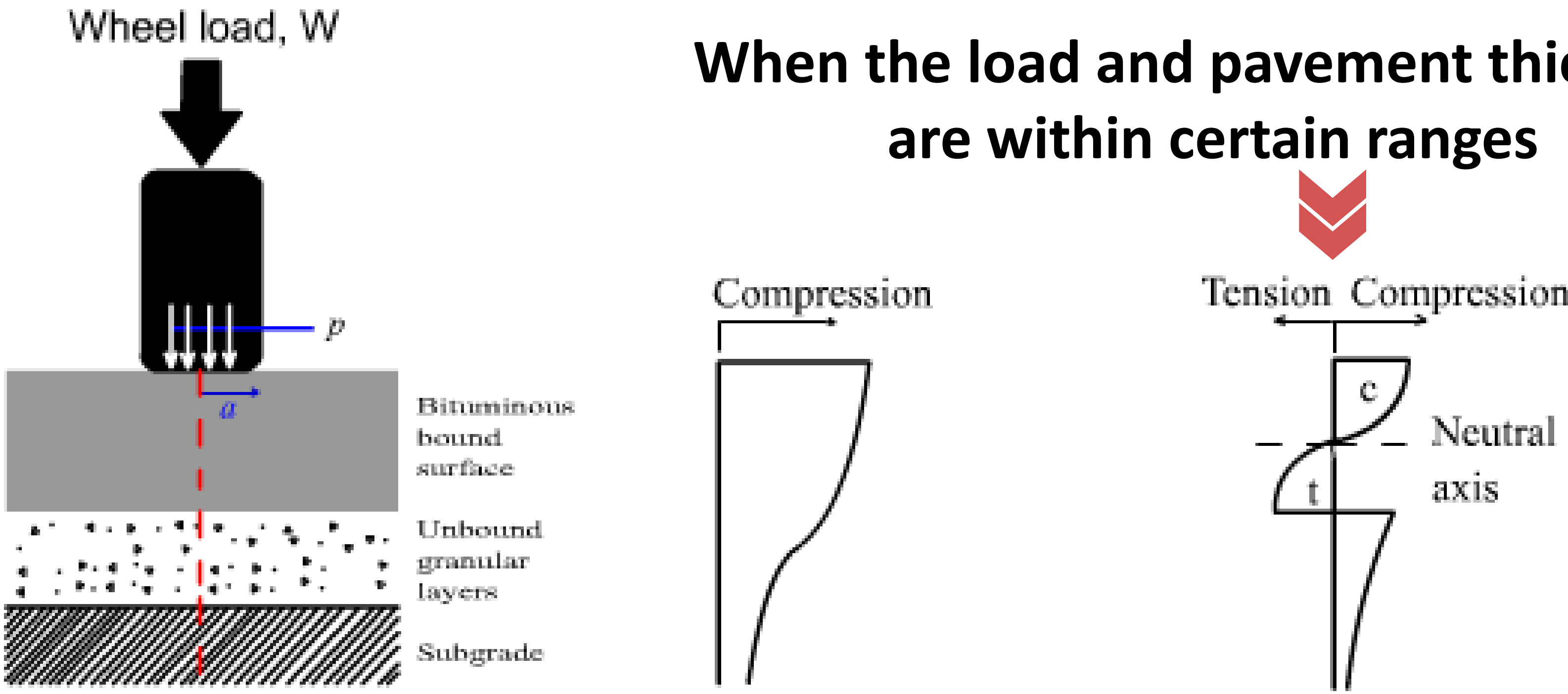
- Pavement structure usually is considered as a multilayered elastic system, with the material in each layer characterized by certain physical properties such as:
  - **Modulus of elasticity**
  - **Resilient modulus**
  - **Poisson ratio**

General Principles of Flexible Pavement Design

- It is assumed that
  - Subgrade layer is infinite in both the horizontal and vertical directions
  - Other layers are finite in the vertical direction and infinite in the horizontal direction
- The application of a wheel load causes a vertical and horizontal stresses

General Principles of Flexible Pavement Design

When the load and pavement thickness are within certain ranges



(a) Pavement layers

(b) Distribution of vertical stress under centerline of wheel load

(c) Distribution of Horizontal stress under centerline of wheel load

p= wheel pressure applied on pavement surface

a= radius of circular area over which wheel load is spread

c = compressive horizontal stress

t = tensile horizontal stress

Figure 4.3 Typical Stress Distribution in a Flexible Pavement Under a Wheel Load

General Principles of Flexible Pavement Design

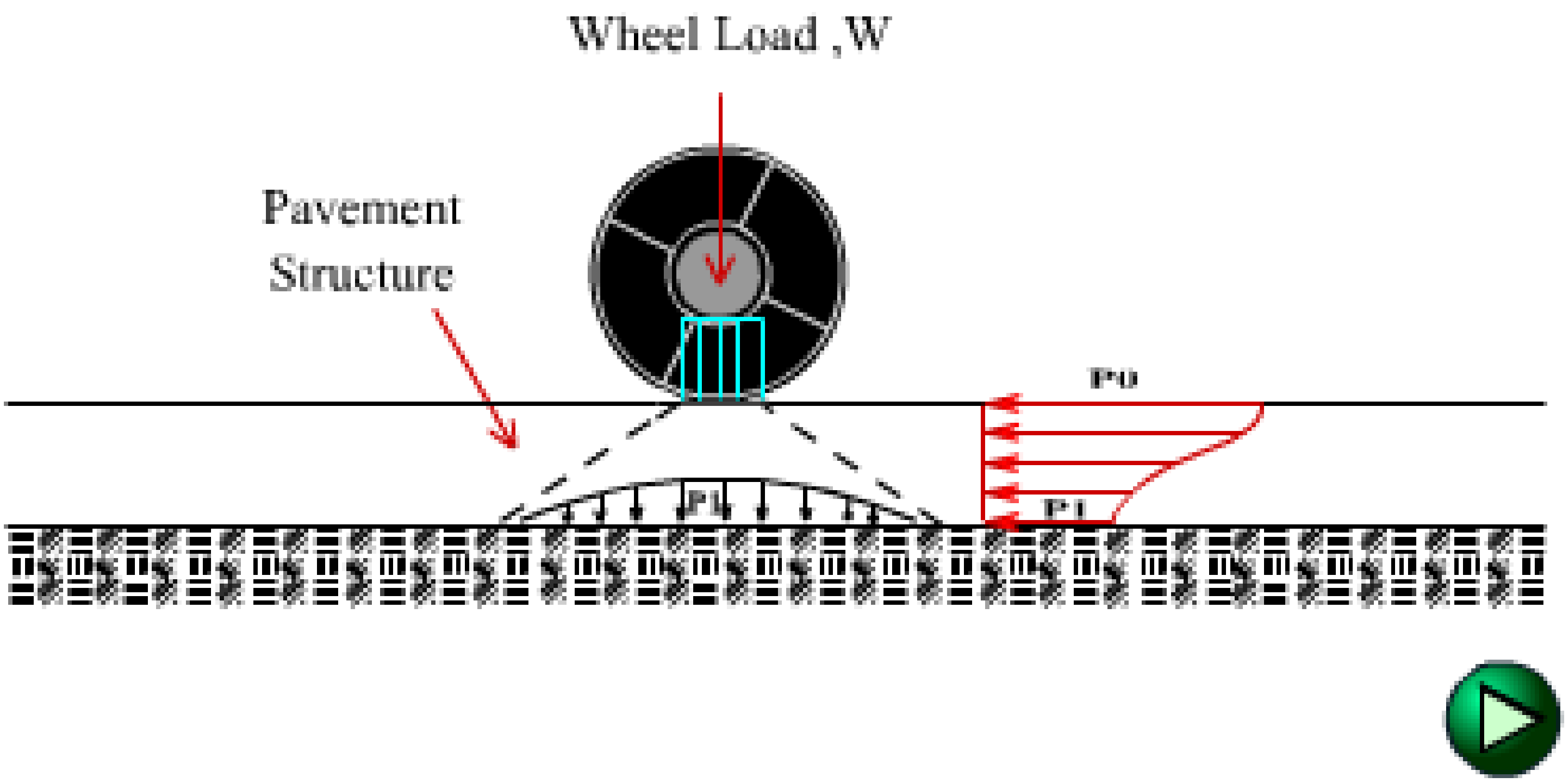


Figure 4.4. Spread of Wheel Load Pressure Through Pavement Structure

General Principles of Flexible Pavement Design

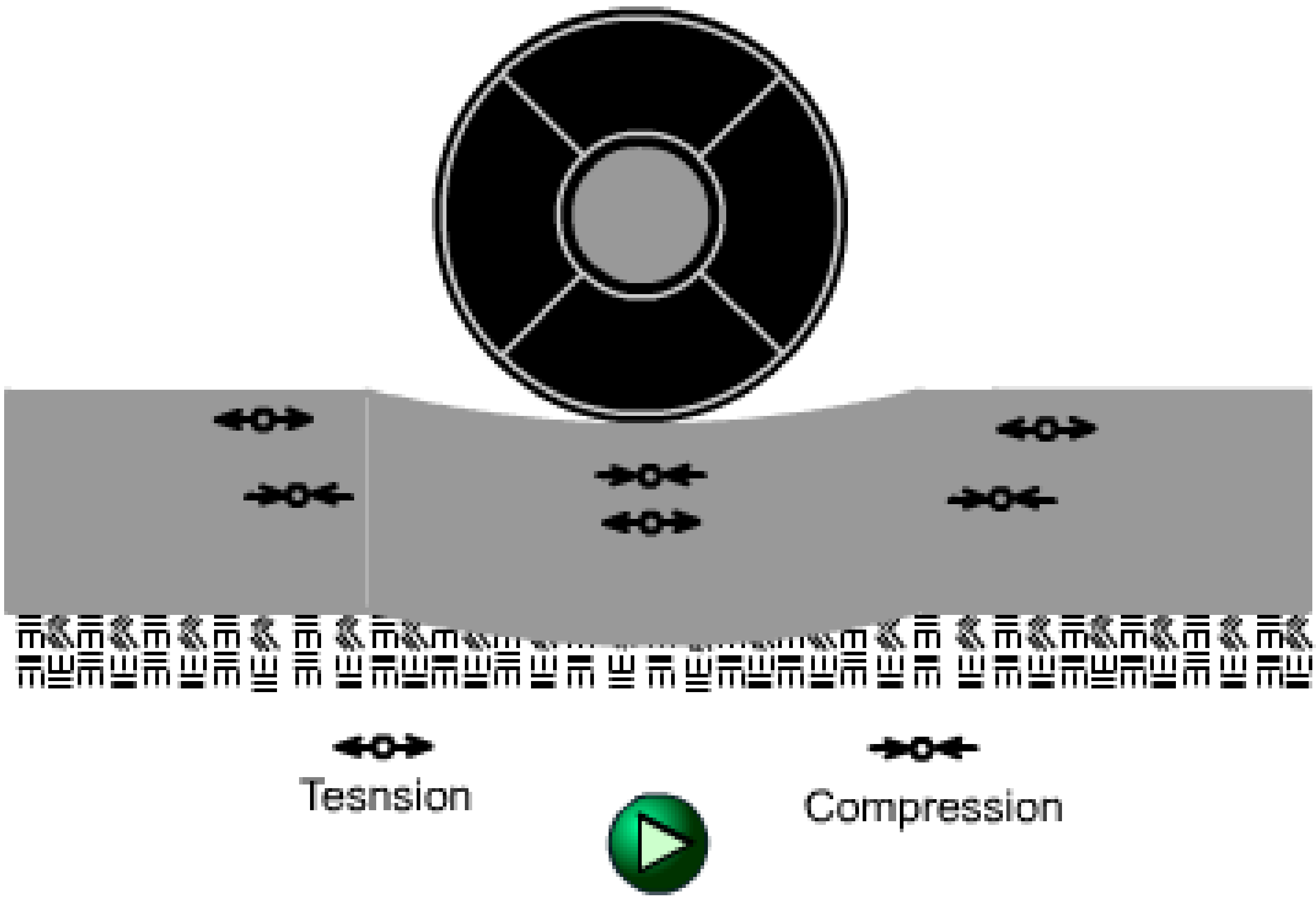


Figure 4.5 Schematic of Tensile and Compressive Stress in Pavement Structure

General Principles of Flexible Pavement Design

- The design of the pavement is generally based on **strain criteria**. It limits both the horizontal and vertical strains
  - Do not need to cause excessive cracking and excessive permanent deformation.
- **Strain Criteria**: are considered in terms of repeated load applications
  - It is important to the development of cracks and permanent deformation of the pavement

AASHTO Method

- It is based primarily on the results of **AASHTO road test that was conducted in Illinois**.
  - Tests were conducted on test sections of flexible and rigid pavements constructed on A-6 subgrade material.
  - The pavement test sections consisted of two small and four larger loops (four-lane divided highway)
  - The tangent sections consisted of a successive set of pavement lengths of different designs, each length being at least 33m.

AASHTO Method

- Single-axle and tandem-axle vehicles were driven until several thousand load repetition had been made.
- Data were collected on the pavement condition which formed the basis of the AASHTO method

AASHTO Method

- **Design considerations**
  - Factors considered in the AASHTO procedure in the 1993 guide are:
    1. **Pavement performance**
    2. **Traffic**
    3. **Roadbed soils (subgrade material)**
    4. **Materials of construction**
    5. **Environment**
    6. **Drainage**
    7. **Reliability**

AASHTO Method

1. **Pavement performance:** Primary factors are:
   - **Structural performance** is related to the physical condition of the pavement with respect to factors that have a negative impact on the pavement
     - » Cracking, faulting, raveling and so forth.
   - **Functional performance** is an indication of how effectively the pavement serves the user.
     - » The main factor considered is riding comfort

AASHTO Method

1. **Pavement performance**
   - To measure the pavement performance, the serviceability performance concept is developed
     - » **Present Serviceability Index PSI (0 – 5)**
   - **PSI** is based on the pavement roughness and distress,
     - » measured in terms of cracking, patching, and rut depth for flexible pavements
     - » Based on the ratings of experienced engineers

AASHTO Method

1. **Pavement performance**
   - Two serviceability indices are used:
     - » **Initial serviceability index (p_i),** which is the serviceability index after the construction of the pavement
       - Value of **4.2** is used for **p_i**
     - » **Terminal serviceability index (p_t),** which is the minimum acceptable value before resurfacing or reconstruction is necessary
       - **2.5 - 3.0** for major highways and **2.0** for lower classification ones

AASHTO Method

1. Pavement performance

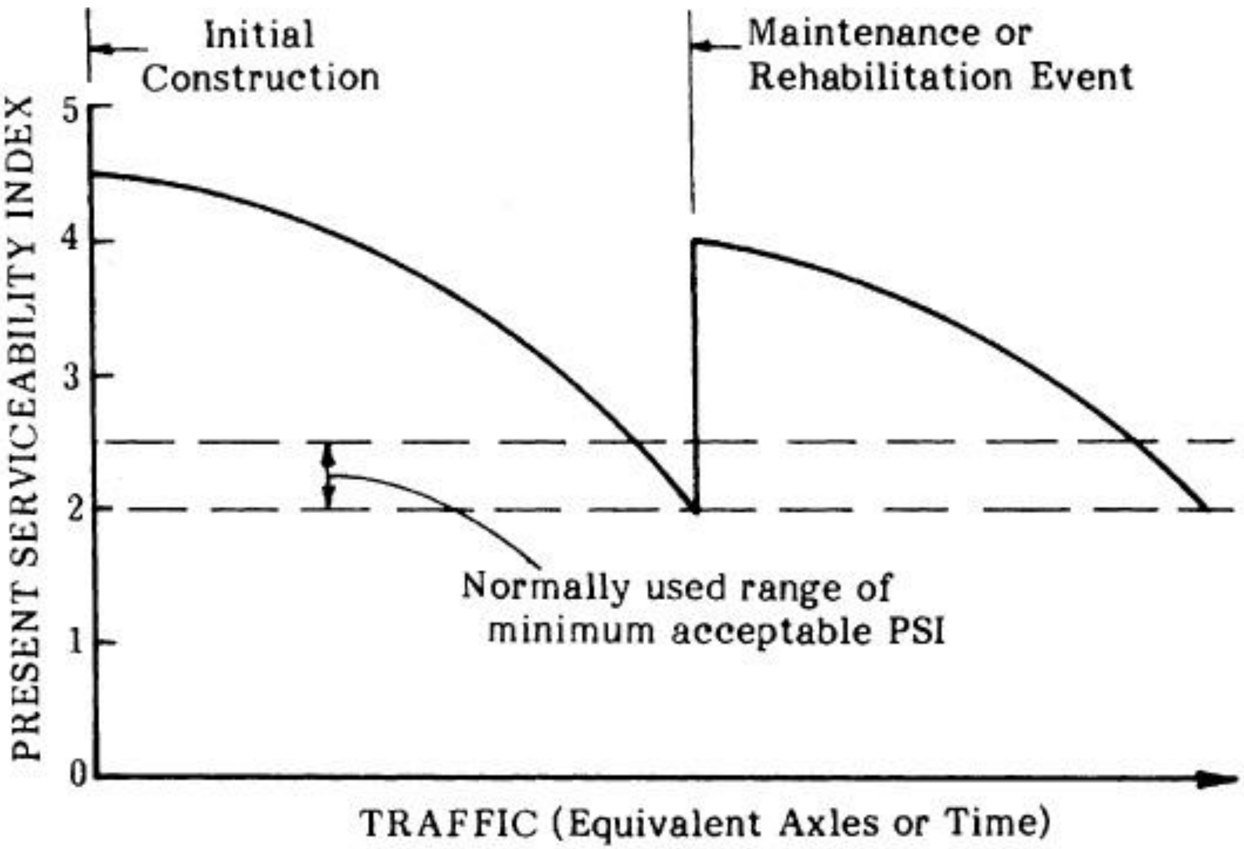
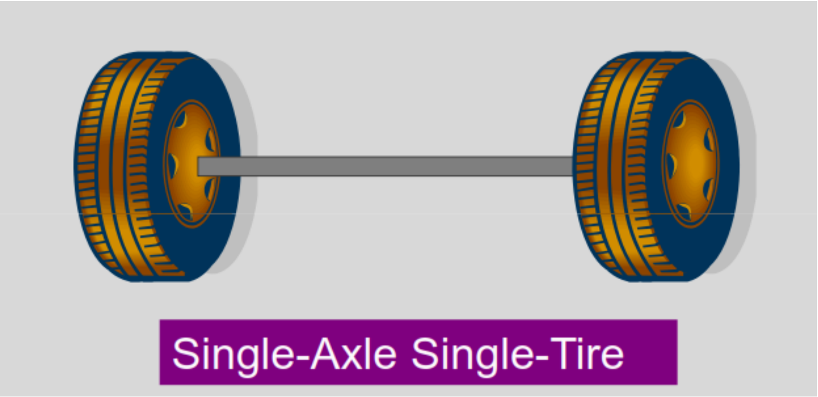


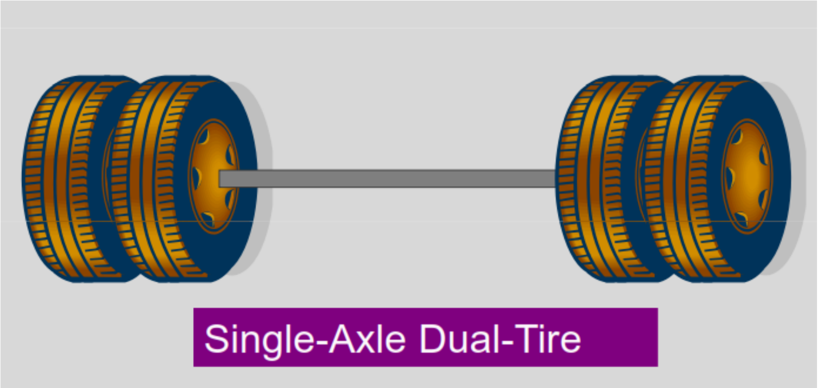
Figure 21.4 Performance History for Pavement Using PSI

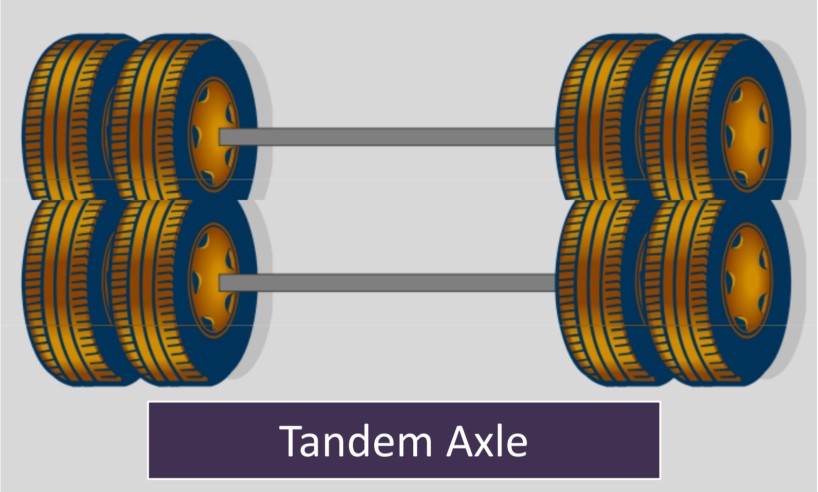
AASHTO Method

2. Traffic:

- Loads are distributed on axles, single or tandem
- **Equivalent Single-Axle Load (ESAL):** number of repetitions of an 18,000-lb (80 kN) single-axle load applied to the pavement on two sets of dual tires
  - » It corresponds to a contact pressure of 70 lb/in
- The effect of any load on the pavement performance can be represented in terms of number of single applications of an 18,000-lb single axle (ESALs)


Single-Axle Single-Tire


Single-Axle Dual-Tire


Tandem Axle

AASHTO Method

2. Traffic:

- **Equivalent Single-Axle Load (ESAL):**

$$\text{ESAL}_i = f_d \times G_{rn} \times \text{AADT}_i \times 365 \times N_i \times F_{Ei}$$

ESAL_i = equivalent accumulated 18,000-lb (80 kN) single-axle load for the axle category i
f_d = design lane factor
G_{rn} = growth factor for a given growth rate r and design period n
AADT_i = first year annual average daily traffic for axle category i
N_i = number of axles on each vehicle in category i
F_{Ei} = load equivalency factor for axle category i

Passenger cars are therefore generally omitted when computing ESAL values.

AASHTO Method

2. **Traffic:**
   - **Load Equivalent factors (F_{Ei})** are based on the terminal serviceability index to be used in the design and the structural number
   - **Table 19.3a** and **Table 19.3b**
   - To determine the ESAL, the number of different types of vehicles expected to use the facility during its lifetime must be known.

AASHTO Method

Table 19.3a Axle Load Equivalency Factors for Flexible Pavements, Single Axles, and p_t of 2.5

Axle Load (kips)	*Pavement Structural Number (SN)* 1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591	.613	.646	.645	.623	.606
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.57	1.49	1.47	1.51	1.55
22	2.48	2.38	2.17	2.09	2.18	2.30
24	3.69	3.49	3.09	2.89	3.03	3.27
26	5.33	4.99	4.31	3.91	4.09	4.48
28	7.49	6.98	5.90	5.21	5.39	5.98
30	10.3	9.5	7.9	6.8	7.0	7.8
32	13.9	12.8	10.5	8.8	8.9	10.0
34	18.4	16.9	13.7	11.3	11.2	12.5
36	24.0	22.0	17.7	14.4	13.9	15.5
38	30.9	28.3	22.6	18.1	17.2	19.0
40	39.3	35.9	28.5	22.5	21.1	23.0
42	49.3	45.0	35.6	27.8	25.6	27.7
44	61.3	55.9	44.0	34.0	31.0	33.1
46	75.5	68.8	54.0	41.4	37.2	39.3
48	92.2	83.9	65.7	50.1	44.5	46.5
50	112.0	102.0	79.0	60.0	53.0	55.0

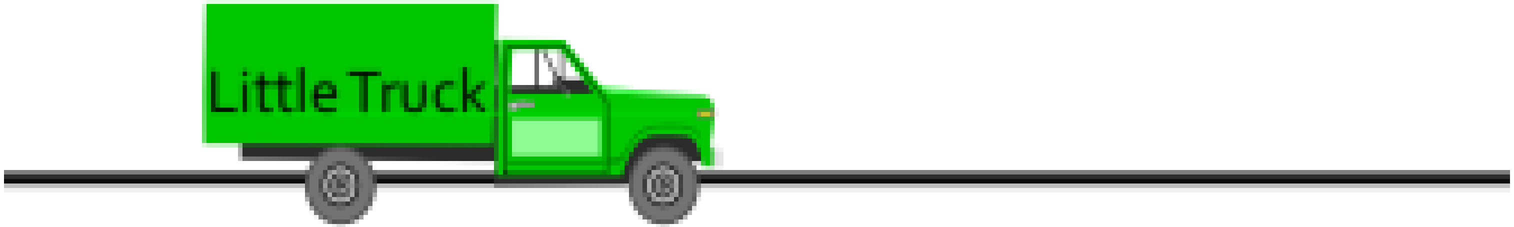
SOURCE: Adapted from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993. Used with permission.

AASHTO Method

Table 19.3b Axle Load Equivalency Factors for Flexible Pavements, Tandem Axles, and p_t of 2.5

Axle Load (kips)	*Pavement Structural Number (SN)*					
	1	*2*	*3*	*4*	*5*	*6*
2	.0001	.0001	.0001	.0000	.0000	.0000
4	.0005	.0005	.0004	.0003	.0003	.0002
6	.002	.002	.002	.001	.001	.001
8	.004	.006	.005	.004	.003	.003
10	.008	.013	.011	.009	.007	.006
12	.015	.024	.023	.018	.014	.013
14	.026	.041	.042	.033	.027	.024
16	.044	.065	.070	.057	.047	.043
18	.070	.097	.109	.092	.077	.070
20	.107	.141	.162	.141	.121	.110
22	.160	.198	.229	.207	.180	.166
24	.231	.273	.315	.292	.260	.242
26	.327	.370	.420	.401	.364	.342
28	.451	.493	.548	.534	.495	.470
30	.611	.648	.703	.695	.658	.633
32	.813	.843	.889	.887	.857	.834
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14
42	2.76	2.67	2.49	2.43	2.51	2.61
44	3.41	3.27	2.99	2.88	3.00	3.16
46	4.18	3.98	3.58	3.40	3.55	3.79
48	5.08	4.80	4.25	3.98	4.17	4.49
50	6.12	5.76	5.03	4.64	4.86	5.28
52	7.33	6.87	5.93	5.38	5.63	6.17
54	8.72	8.14	6.95	6.22	6.47	7.15
56	10.3	9.6	8.1	7.2	7.4	8.2
58	12.1	11.3	9.4	8.2	8.4	9.4
60	14.2	13.1	10.9	9.4	9.6	10.7
62	16.5	15.3	12.6	10.7	10.8	12.1
64	19.1	17.6	14.5	12.2	12.2	13.7
66	22.1	20.3	16.6	13.8	13.7	15.4
68	25.3	23.3	18.9	15.6	15.4	17.2
70	29.0	26.6	21.5	17.6	17.2	19.2
72	33.0	30.3	24.4	19.8	19.2	21.3
74	37.5	34.4	27.6	22.2	21.3	23.6
76	42.5	38.9	31.1	24.8	23.7	26.1
78	48.0	43.9	35.0	27.8	26.2	28.8
80	54.0	49.4	39.2	30.9	29.0	31.7
82	60.6	55.4	43.9	34.4	32.0	34.8
84	67.8	61.9	49.0	38.2	35.3	38.1
86	75.7	69.1	54.5	42.3	38.8	41.7
88	84.3	76.9	60.6	46.8	42.6	45.6
90	93.7	85.4	67.1	51.7	46.8	49.7

EXAMPLE



67 kN 15,000 lb 0.48 ESAL	+	27 kN 6,000 lb 0.01 ESAL	=	0.49 ESAL

151 kN 34,000 lb 1.10	+	151 kN 34,000 lb 1.10	+	54 kN 12,000 lb 0.19	=	2.39 ESAL

AASHTO Method

2. Traffic:

- The total ESAL during the design period depends on:
  - » **Design period**: number of years the pavement will effectively continue to carry the traffic load without requiring an overlay
    - Flexible pavements are designed for **a 20-years**
  - » **Traffic growth factors**: Since traffic volume does not remain constant over the design period, it is essential that the rate of growth be determined

AASHTO Method

2. Traffic:

» **Traffic growth factors G_{rn}**: Since traffic volume does not remain constant over the design period, it is essential that the rate of growth be determined

- G_{rn} can be obtained from regional planning agencies or from state highway departments
- In the United States, overall G_{rn} is between 3 and 5% per year (up to 10% for interstate highways)

$$G_{rn} = [(1 + r)^n - 1]/r$$

$r = \frac{i}{100}$ and is not zero.

i = growth rate

n = design life, yrs

If annual growth is zero, growth factor = design period

AASHTO Method

2. Traffic:

» **Traffic growth factors G_{rn}**

Table 19.4 Growth Factors

Design Period, Years (n)	Annual Growth Rate, Percent (r) No Growth	2	4	5	6	7	8	10
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.02	2.04	2.05	2.06	2.07	2.08	2.10
3	3.0	3.06	3.12	3.15	3.18	3.21	3.25	3.31
4	4.0	4.12	4.25	4.31	4.37	4.44	4.51	4.64
5	5.0	5.20	5.42	5.53	5.64	5.75	5.87	6.11
6	6.0	6.31	6.63	6.80	6.98	7.15	7.34	7.72
7	7.0	7.43	7.90	8.14	8.39	8.65	8.92	9.49
8	8.0	8.58	9.21	9.55	9.90	10.26	10.64	11.44
9	9.0	9.75	10.58	11.03	11.49	11.98	12.49	13.58
10	10.0	10.95	12.01	12.58	13.18	13.82	14.49	15.94
11	11.0	12.17	13.49	14.21	14.97	15.78	16.65	18.53
12	12.0	13.41	15.03	15.92	16.87	17.89	18.98	21.38
13	13.0	14.68	16.63	17.71	18.88	20.14	21.50	24.52
14	14.0	15.97	18.29	19.16	21.01	22.55	24.21	27.97
15	15.0	17.29	20.02	21.58	23.28	25.13	27.15	31.77
16	16.0	18.64	21.82	23.66	25.67	27.89	30.32	35.95
17	17.0	20.01	23.70	25.84	28.21	30.84	33.75	40.55
18	18.0	21.41	25.65	28.13	30.91	34.00	37.45	45.60
19	19.0	22.84	27.67	30.54	33.76	37.38	41.45	51.16
20	20.0	24.30	29.78	33.06	36.79	41.00	45.76	57.28
25	25.0	32.03	41.65	47.73	54.86	63.25	73.11	98.35
30	30.0	40.57	56.08	66.44	79.06	94.46	113.28	164.49
35	35.0	49.99	73.65	90.32	111.43	138.24	172.32	271.02

SOURCE: *Thickness Design–Asphalt Pavements for Highways and Streets,* Manual Series No. 1, The Asphalt Institute, Lexington, KY, February 1991. Used with permission.

AASHTO Method

2. Traffic

» **Design Lane Factor (f_d)**: The portion of the total ESAL acting on the design lane. determined

- **Two-lane highways: Either lane**
- **Multilane highways: Outside lane**

• The identification of the design lane is important because:

- **More trucks might travel in one direction**
- **Trucks may travel heavily loaded in one direction and empty in the other direction.**

AASHTO Method

Table 4.5 Percentage of Total Truck Traffic on Design Lane

Number of Traffic Lanes (Tow Directions)	Percentage of Trucks in Design Lane
2	50
4	45 (35-48)*
6 or more	40 (25-48)*

* Probable range

AASHTO Method

Example 19.1 Computing Accumulated Equivalent Single-Axle Load for a Proposed Eight-Lane Highway Using Load Equivalency Factors

An eight-lane divided highway is to be constructed on a new alignment. Traffic volume forecasts indicate that the average annual daily traffic (AADT) in both directions during the first year of operation will be 12,000 with the following vehicle mix and axle loads.

Passenger cars (1000 lb/axle) = 50%

2-axle single-unit trucks (6000 lb/axle) = 33%

3-axle single-unit trucks (10,000 lb/axle) = 17%

The vehicle mix is expected to remain the same throughout the design life of the pavement. If the expected annual traffic growth rate is 4% for all vehicles, determine the design ESAL, given a design period of 20 years. The percent of traffic on the design lane is 45%, and the pavement has a terminal serviceability index (p_t) of 2.5 and SN of 5.

AASHTO Method

The following data apply:

Growth factor = 29.78 (from Table 19.4)
Percent truck volume on design lane = 45
Load equivalency factors (from Table 19.3)
Passenger cars (1000 lb/axle) = 0.00002 (negligible)
2-axle single-unit trucks (6000 lb/axle) = 0.010
3-axle single-unit trucks (10,000 lb/axle) = 0.088

Solution: The ESAL for each class of vehicle is computed from Eq. 19.2.

$$\text{ESAL} = f_d \times G_{jt} \times \text{AADT} \times 365 \times N_i \times F_{Ei}$$

$$\text{2-axle single-unit trucks} = 0.45 \times 29.78 \times 12{,}000 \times 0.33 \times 365 \times 2 \times 0.010 = 0.3874 \times 10^6$$

$$\text{3-axle single-unit trucks} = 0.45 \times 29.78 \times 12{,}000 \times 0.17 \times 365 \times 3 \times 0.0877 = 2.6343 \times 10^6$$

Thus,

$$\text{Total ESAL} = 3.0217 \times 10^6$$

It can be seen that the contribution of passenger cars to the ESAL is negligible. Passenger cars are therefore omitted when computing ESAL values. This example illustrates the conversion of axle loads to ESAL using axle load equivalency factors.

AASHTO Method

2. Traffic:

– The equivalent 18,000-lb load can also be determined from the vehicle type, if the axle load is unknown, by using a **truck factor** for that vehicle type.

» **Truck factor:** number of 18,000-lb single-load applications caused by a single passage of a vehicle.

$$\text{Truck factor} = \frac{\sum(\text{number of axles} \times \text{load equivalency factor})}{\text{number of vehicles}}$$

$$\text{ESAL} = \text{AADT} * 365 * \text{Design Lane Factor} * \text{Truch Factor} * \text{Growth Factor}$$

AASHTO Method

– Truck Factor: Example

Table 6.25 Average Truck Factors Compiled from FHWA Data [Ref. 6A-1]

Vehicle Types	Truck Factors (ESALs/truck)				
	Rural Highways			Urban Highways	Combined
	Interstate	Other	All	All	All
1. Single-units					
(a) 2-axle, 4-tire	0.02	0.02	0.03	0.03	0.02
(b) 2-axle, 6-tire	0.19	0.21	0.20	0.26	0.21
(c) 3-axles or more	0.56	0.73	0.67	1.03	0.73
(d) All single-units	0.07	0.07	0.07	0.09	0.07
2. Tractor semi-trailers					
(a) 3-axle	0.51	0.47	0.48	0.47	0.48
(b) 4-axle	0.62	0.83	0.70	0.89	0.73
(c) 5-axles or more	0.94	0.98	0.95	1.00	0.95
(d) All multiple units	0.93	0.97	0.94	1.00	0.95
3. All trucks	0.49	0.31	0.42	0.30	0.40

AASHTO Method

3. Roadbed Soils (Subgrade Material)

– Resilient modulus (***M_r***) of the soil is used to define its property.

» CBR (or R) value of the soil can be converted to an equivalent ***M_r*** value using the following conversion factors:

M_r (lb/in^2) = 1500 CBR (for fine-grain soils with soaked CBR of 10 or less)

M_r (lb/in^2) = 1000 + 555 R value (for $R \leq 20$)

Metric

– M_r (kN/m^2) = 220 CBR (for fine-grain soil with soaked CBR of 10 or less)

– M_r (kN/m^2) = 145 + 80.4 R (for $R \leq 20$)

AASHTO Method

4. Materials of Construction

– The materials used for construction can be classified into:

① **Surface construction material**

② **Base construction material**

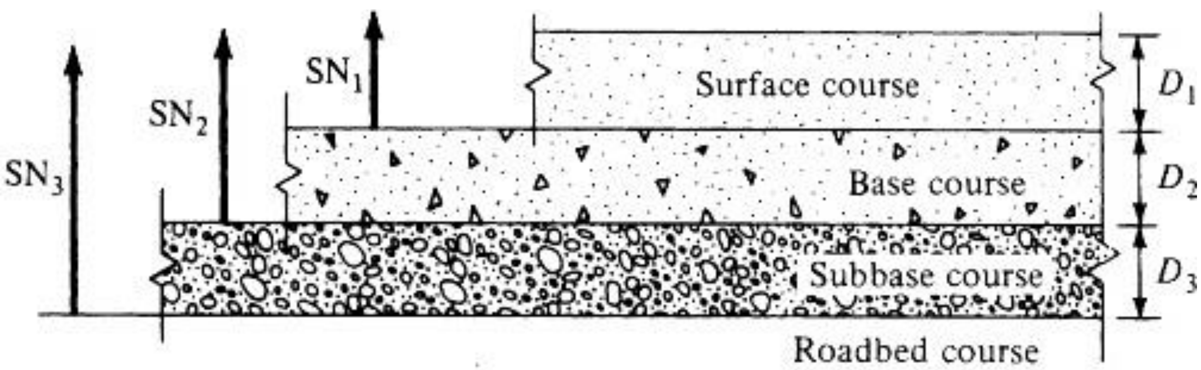
③ **Subbase construction material**

Table 4.6 Untreated Aggregate Base and Subbase Quality Requirements

Test	Test Requirements	
	Subbase	Base
CBR, minimum	20	80
Liquid limit, maximum	25	25
Plasticity index, minimum	6	NP
Sand equivalent, minimum	25	35
Passing No.200 sieve, maximum	12	7

AASHTO Method

- **Structural Number:** The objective of the design using AASHTO method is to determine a flexible pavement Structural Number (SN) adequate to carry the projected design ESAL.



4. Materials of Construction

① Surface course construction material

- Most commonly-used material is a hot plant mix of asphalt cement and dense-graded aggregates with a maximum size of 1 inch.
- **The quality of the material used is determined in terms of the layer coefficient (a_1)**

Figure 19.5

$$SN_1 = a_1 D_1$$

4. Materials of Construction

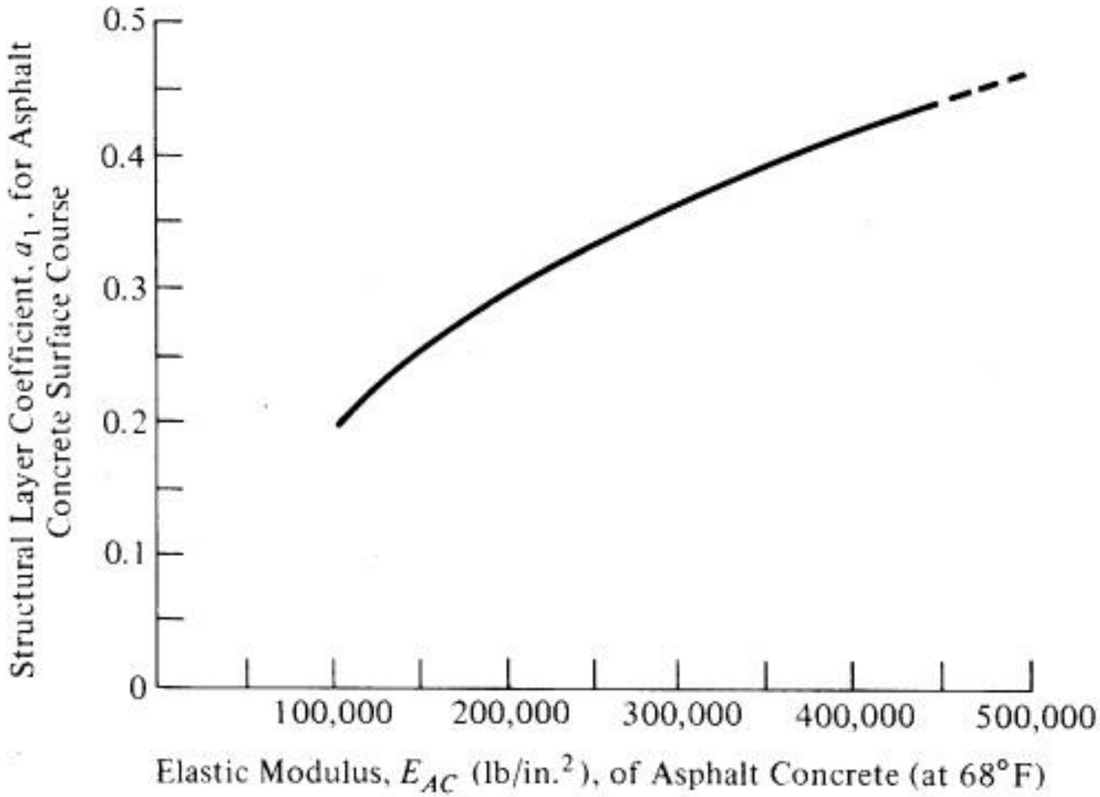


Figure 19.5 Chart for Estimating Structural Layer Coefficient of Dense-Graded/Asphalt Concrete Based on the Elastic (Resilient) Modulus

SOURCE: Redrawn from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993. Used with permission.

AASHTO Method

4. Materials of Construction

② Base course construction material

» The quality of the material used is determined in terms of the layer coefficient (a_2)

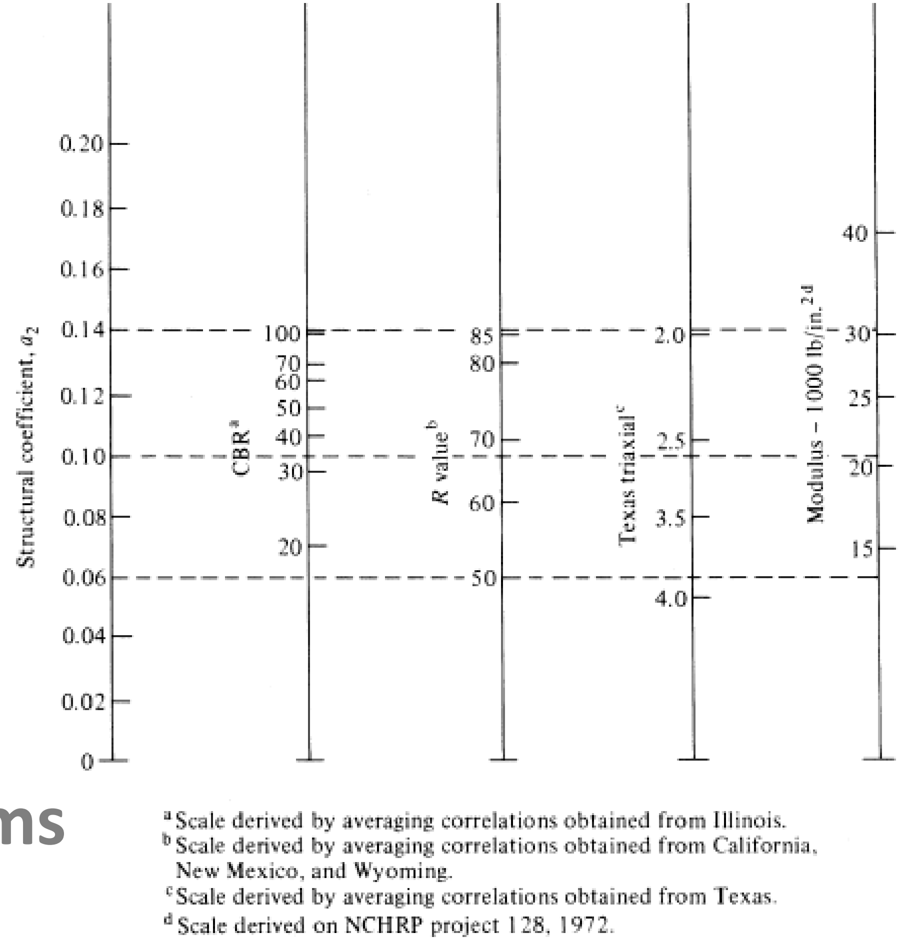


Figure 19.4

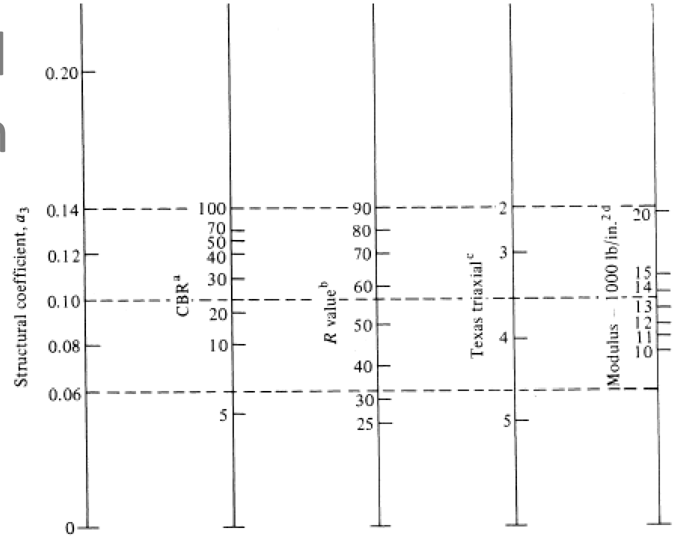
$$SN_2 = a_1 D_1 + a_2 D_2 m_2$$

4. Materials of Construction

③ Subbase construction material

- » The quality of the material used is determined in terms of the layer coefficient (a_3)
  - It is used to convert actual thickness of subbase to an equivalent **SN**
- » Layer coefficients are usually assigned, based on the description of the material used.

$$SN_3 = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$



[a] Scale derived from correlations from Illinois.
[b] Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico, and Wyoming.
[c] Scale derived from correlations obtained from Texas.
[d] Scale derived on NCHRP project 1 28, 1972.

Figure 19.3

AASHTO Method

5. Environment

- Main environmental factors used in the AASHTO method:
  - » **Temperature:** stresses induced by thermal action, changes in the creep properties, and the effect of freezing and thawing of the subgrade soil.
  - » **Rainfall:** penetration of the surface water into the underlying material. (presented later under "Drainage")

AASHTO Method

5. Environment

- **Temperature:**
  - » Weakening of underlying material during the thaw period, is a major factor in determining the strength of the underlying materials.
    - Normal modulus (modulus during summer and fall seasons) of materials susceptible to frost action can be reduced by 50 percent to 80 percent.
  - » **Effective Annual Roadbed Soil Resilient Modulus:** It take into consideration the variation during the year in the resilient modulus

AASHTO Method

» **Effective Annual Roadbed Soil Resilient Modulus:**

- It is equivalent to the combined effect of different seasonal moduli during the year

» **According to AASHTO, the effective modulus is estimated as follows:**

a. Relationship between moisture content and the resilient modulus using laboratory tests.

b. Resilient modulus is estimated or each season based on the estimated in site moisture content during the season being considered.

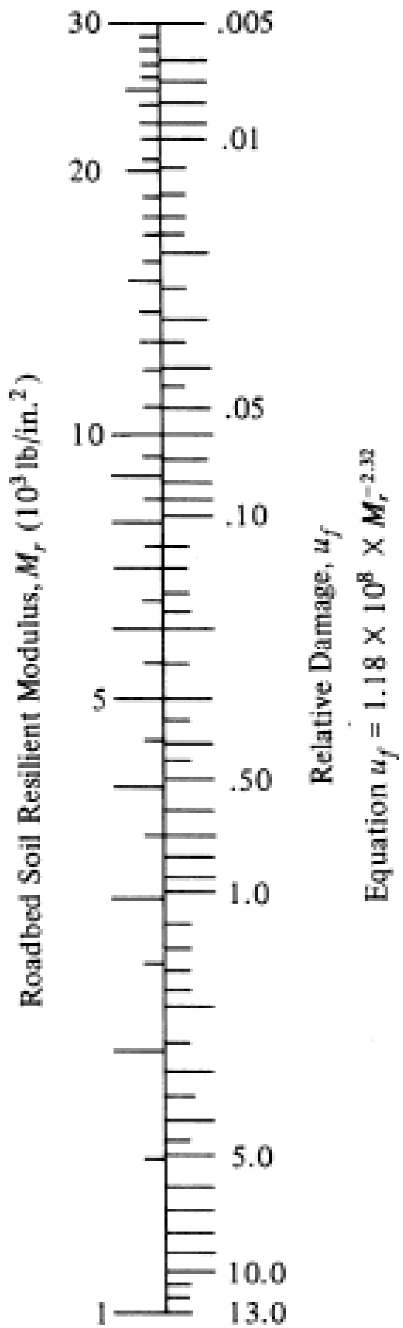
c. Resilient modulus is estimated for the whole year

AASHTO Method

d. Using **Figure 19.6**, relative damage u_f for each time period is determined

e. The mean relative damage u_f is then computed

f. Find the effective subgrade resilient modulus corresponding to the mean u_f



AASHTO Method

» Effective Annual Roadbed Soil Resilient Modulus:

Example 19.2 Computing Effective Resilient Modulus

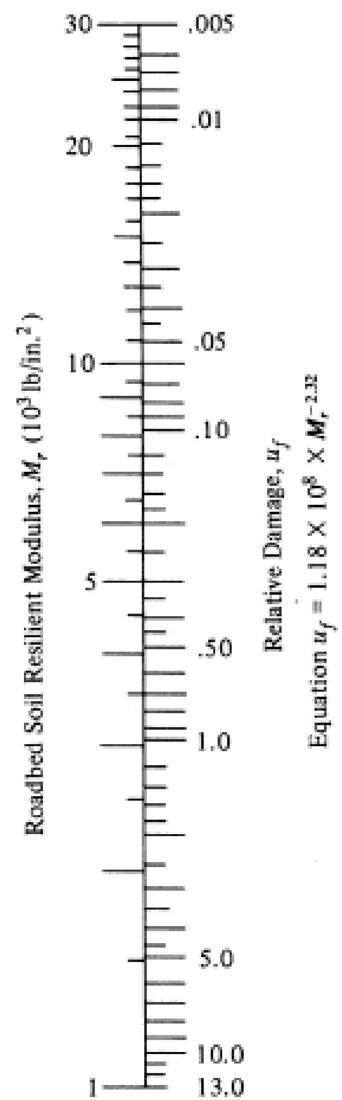
Figure 19.6 shows roadbed soil resilient modulus M_r for each month estimated from laboratory results correlating M_r with moisture content. Determine the effective resilient modulus of the subgrade.

Solution: Note that in this case, the moisture content does not vary within any one month. The solution of the problem is given in Figure 19.6. The value of u_f for each M_r is obtained directly from the chart. The mean relative damage u_f is 0.133, which in turn gives an effective resilient modulus of 7250 lb/in^2.

AASHTO Method

» **Effective Annual Roadbed Soil Resilient Modulus:**

Month	Roadbed Soil Modulus M_r (lb/in.^{2})	Relative Damage u_f
Jan.	22000	0.01
Feb.	22000	0.01
Mar.	5500	0.25
Apr.	5000	0.30
May	5000	0.30
June	8000	0.11
July	8000	0.11
Aug.	8000	0.11
Sept.	8500	0.09
Oct.	8500	0.09
Nov.	6000	0.20
Dec.	22000	0.01
Summation: $\Sigma u_f =$		1.59



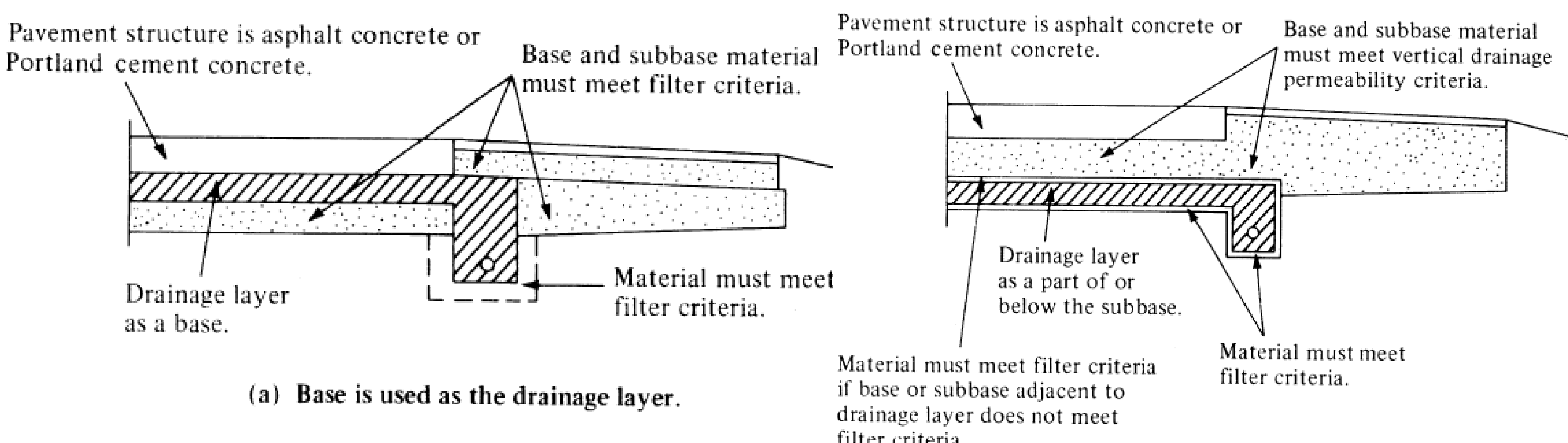
$$\text{Average } \bar{u}_f = \frac{\Sigma u_f}{n} = \frac{1.59}{12} = 0.133$$

Effective Roadbed Soil Resilient Modulus, M_r (lb/in.^{2}) = <u>7250</u> (corresponds to $\bar{u}_f$)

AASHTO Method

6. Drainage

- Water has effects on the strength of the base material and roadbed soil.
- Provide a suitable drainage layer for the rapid drainage of the free water (non-capillary) from the pavement structure



(a) Base is used as the drainage layer.

AASHTO Method

6. Drainage

- The modification is done by adding a factor m_i for the base and subbase layer coefficients (a_2 and a_3).
- m_i is based on:
  - » **Percentage of time during which the pavement structure will be near saturation**
  - » **Quality of drainage,** which depends on the time it takes to drain the base layer to 50 percent of saturation

AASHTO Method

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.
SOURCE: Adapted with permission from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

Table 19.6 Recommended m_i Values

	Percent of Time Pavement Structure Is Exposed to Moisture Levels Approaching Saturation			
Quality of Drainage	*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

SOURCE: Adapted with permission from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

AASHTO Method

6. Reliability

- AASHTO method is based on the assumed growth rates, which may not be accurate
- **Reliability factor (*F_R%*)**: It considers the possible uncertainties in traffic prediction and performance prediction

$$\log_{10} F_R = -Z_R S_o$$

Z_R = standard normal variate for a given reliability (R%)
S_o = estimated overall standard deviation

S_0^2 accounts for the chance variation in the traffic forecast and in actual pavement performance for a given design period

AASHTO Method

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

Note: Results based on a survey of the AASHTO Pavement Design Task Force.
SOURCE: Adapted with permission from *AASHTO Guide for Design of Pavement Structures,* American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

Table 19.8 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

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

AASHTO Method

- **Structural Design**
  - AASHTO Method aims at determining a flexible pavement **Structural Number (SN)** adequate to carry the projected design ESAL.
  - The designer selects the type of surface used, which can be either:
    - » **asphalt concrete,**
    - » **single surface and**
    - » **double surface treatment**

It is used for ESALs greater than 50,000 for the performance period

AASHTO Method

- **Structural Design**
  - **Structural Number (SN)**

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

m_i = drainage coefficient for layer i

a_1, a_2, a_3 = layer coefficients representative of surface, base, and subbase course, respectively

D_1, D_2, D_3 = actual thickness in inches of surface, base, and subbase courses, respectively

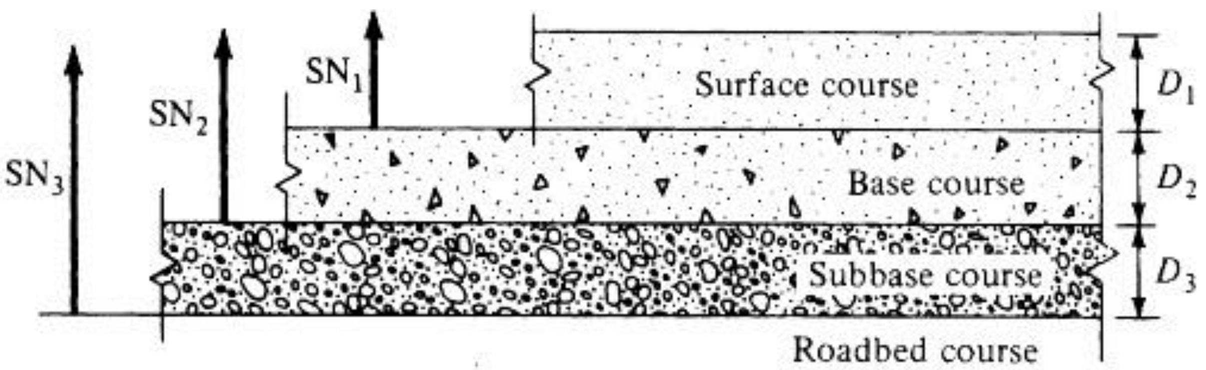


Figure 19.9 Procedure for Determining Thicknesses of Layers Using a Layered Analysis Approach

AASHTO Method

- **Structural Design**
  - **Structural Number (SN):** The basic design equation given in AASHTO 1993 guide is (which can be solved using Figure 19.8):

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

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
$\Delta \mathrm{PSI} = p_i - p_t$

AASHTO Method

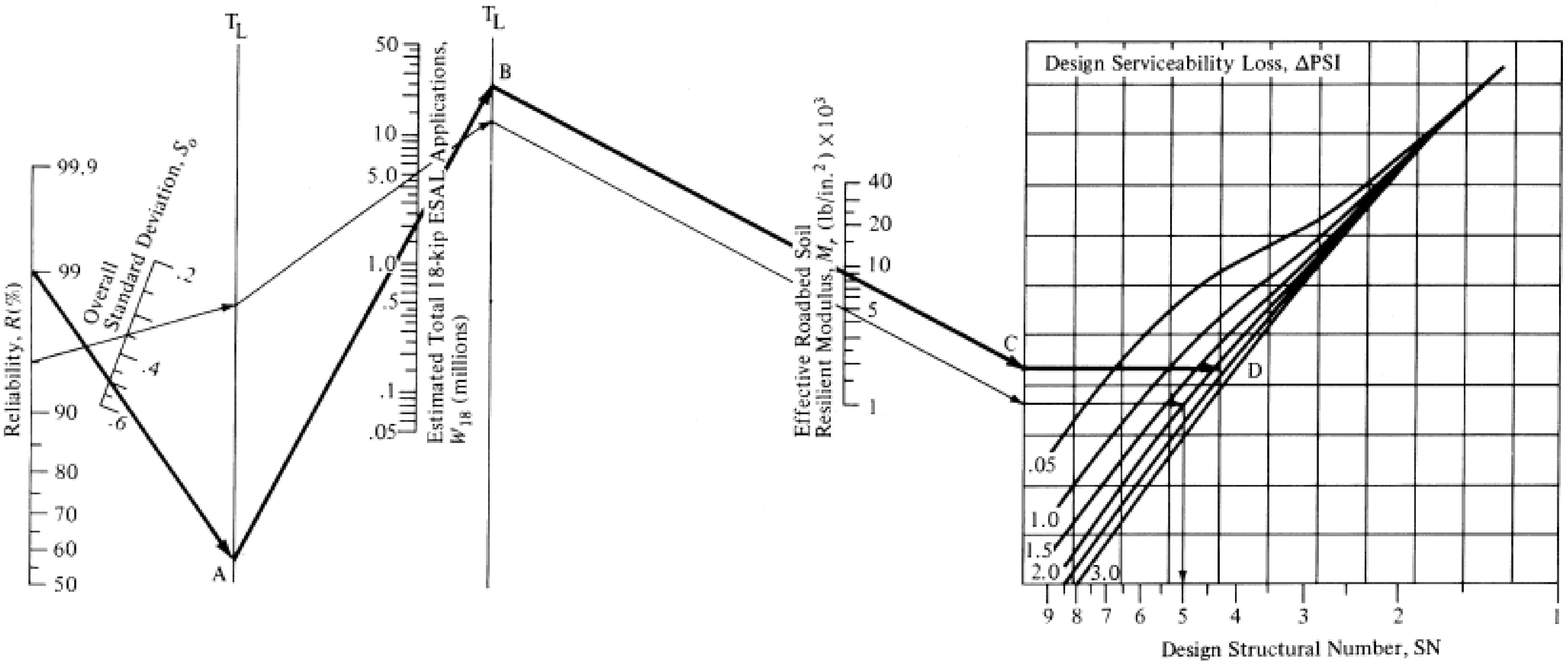


Figure 19.8 Design Chart for Flexible Pavements Based on Using Mean Values for each Input

SOURCE: Redrawn from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993. Used with permission.

AASHTO Method

Example 19.3 Designing a Flexible Pavement Using the AASHTO Method

A flexible pavement for an urban interstate highway is to be designed using the 1993 AASHTO guide procedure to carry a design ESAL of 2×10^6. 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 for 30% of the time. The following additional information is available:

Resilient modulus of asphalt concrete at 68°F = 450,000 lb/in^2
CBR value of base course material = 100, M_r = 31,000 lb/in^2
CBR value of subbase course material = 22, M_r = 13,500 lb/in^2
CBR value of subgrade material = 6

Determine a suitable pavement structure, M_r of subgrade $= 6 \times 1500$ lb/in^2 = 9000 lb/in^2.

AASHTO Method

Solution: Since the pavement is to be designed for an interstate highway, the following assumptions are made.

Reliability level (R) = 99% (range is 85 to 99.9 from Table 19.7)
Standard deviation (S_o) = 0.49 (range is 0.4 to 0.5)
Initial serviceability index p_i = 4.5
Terminal serviceability index p_t = 2.5

The nomograph in Figure 19.8 is used to determine the design SN through the following steps.

Step 1. Draw a line joining the reliability level of 99% and the overall standard deviation S_o of 0.49, and extend this line to intersect the first T_L line at point A.

Step 2. Draw a line joining point A to the ESAL of 2×10^6, and extend this line to intersect the second T_L line at point B.

Step 3. Draw a line joining point B and resilient modulus (M_r) of the roadbed soil, and extend this line to intersect the design serviceability loss chart at point C.

Step 4. Draw a horizontal line from point C to intersect the design serviceability loss (ΔPSI) curve at point D. In this problem, ΔPSI = 4.5 – 2.5 = 2.

AASHTO Method

Step 5. Draw a vertical line to intersect the design SN, and read this value SN = 4.4.

Step 6. Determine the appropriate structure layer coefficient for each construction material.

(a) Resilient value of asphalt = 450,000 lb/in^2. From Figure 19.5, $a_1 = 0.44$.

(b) CBR of base course material = 100. From Figure 19.4, $a_2 = 0.14$.

(c) CBR of subbase course material = 22. From Figure 19.3, $a_3 = 0.10$.

Step 7. Determine appropriate drainage coefficient m_i. Since only one set of conditions is given for both the base and subbase layers, the same value will be used for m_1 and m_2. The time required for water to drain from within pavement = 1 week, and from Table 19.5, drainage quality is fair. The percentage of time pavement structure will be exposed to moisture levels approaching saturation = 30, and from Table 19.6, $m_i = 0.80$.

Step 8. Determine appropriate layer thicknesses from Eq. 19.6:

$$= a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

AASHTO Method

It can be seen that several values of D_1, D_2, and D_3 can be obtained to satisfy the SN value of 4.40. Layer thicknesses, however, are usually rounded up to the nearest 0.5 inches.

The selection of different layer thicknesses also should be based on constraints associated with maintenance and construction practices so that a practical design is obtained. For example, it is normally impractical and uneconomical to construct any layer with a thickness less than some minimum value. Table 19.9 on page 1052 lists minimum thicknesses suggested by AASHTO.

Taking into consideration that a flexible pavement structure is a layered system, the determination of the different thicknesses should be carried out as indicated in Figure 19.9. The required SN above the subgrade is first determined, and then the required SNs above the base and subbase layers are determined using the appropriate strength of each layer. The minimum allowable thickness of each layer can then be determined using the differences of the computed SNs as shown in Figure 19.9.

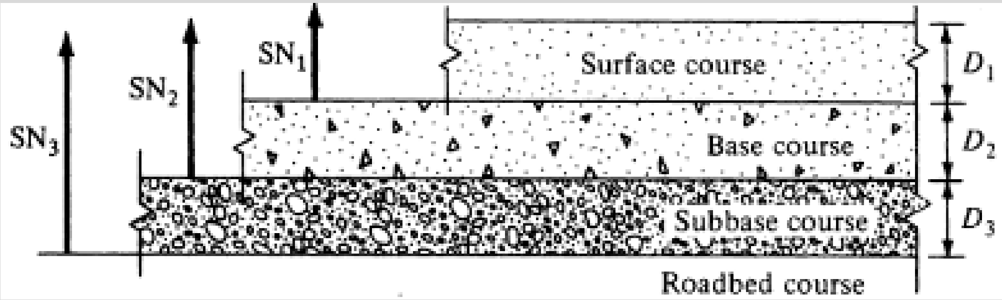


Figure 19.9 Procedure for Determining Thicknesses of Layers Using a Layered Analysis Approach

AASHTO Method

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

SOURCE: Adapted with permission from *AASTHO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

Using the appropriate values for M_r in Figure 19.8, we obtain $SN_3 = 4.4$ and $SN_2 = 3.8$. Note that when SN is assumed to compute ESAL, the assumed and computed SN_3 values must be approximately equal. If these are significantly different, the computation must be repeated with a new assumed SN.

We know

$$M_r \text{ for base course} = 31{,}000 \text{ lb/in.}^2$$

Using this value in Figure 19.8, we obtain

$$SN_1 = 2.6$$

AASHTO Method

giving

$$D_1 = \frac{2.6}{0.44} = 5.9 \text{ in.}$$

Using 6 in., for the thickness of the surface course,

$$D_1^* = 6 \text{ in.}$$

$$SN_1^* = a_1 D_1^* = 0.44 \times 6 = 2.64$$

$$D_2^* \geq \frac{SN_2 - SN_1^*}{a_2 m_2} \geq \frac{3.8 - 2.64}{0.14 \times 0.8} \geq 10.36 \text{ in.} \qquad \text{(use 12 in.)}$$

$$SN_2^* = 0.14 \times 0.8 \times 12 + 2.64 = 1.34 + 2.64$$

$$D_3^* = \frac{SN_3 - SN_2^*}{a_3 m_3} = \frac{4.4 - (2.64 + 1.34)}{0.1 \times 0.8} = 5.25 \text{ in.} \qquad \text{(use 6 in.)}$$

$$SN_3^* = 2.64 + 1.34 + 6 \times 0.8 \times 0.1 = 4.46$$

The pavement will therefore consist of 6 in. asphalt concrete surface, 12 in. granular base, and 6 in. subbase.

*An asterisk with D or SN indicates that it represents the value actually used which must be equal to or greater than the required value.

Mechanistic-Empirical Pavement Design

- It uses empirical relationships between cumulative damage and pavement distress to determine the adequacy of a pavement structure to carry the expected traffic load.
- It is iterative process:
  - » The designer first selects a trial design
    - considering site conditions that include traffic, climate, and subgrade
  - » Evaluates it for adequacy with certain performance criteria and reliability values
    - based on predicted distresses and smoothness of the pavement