TOPIC 9

Structural Design of Pavements

Part 1

Structural Design of Flexible Pavements

Introduction

- ❖ Highway pavements are divided into two main categories:
  1. Rigid (Wearing Surface made of PCC)
  2. Flexible (Wearing Surface made of Bituminous Materials)
- ❖ Wearing Surface of Rigid Pavements acts like a beam over any irregularities in the underlying supporting material.
- ❖ Wearing Surface of flexible pavements remain in contact with the underlying material
- ❖ Traffic loads are transferred by the wearing surface to the underlying supporting materials through the interlocking of aggregates, the frictional effect of granular materials, and cohesion of fine materials.
- ❖ Flexible pavements are further divided into three subgroups:

i. high type – Support expected traffic load without visible distress

ii. Intermediate type - range from surface treated to those with qualities just below that of high type

iii. low type - low-cost roads and have wearing surfaces that range from untreated to loose natural materials to surface treated earth.

Soil Stabilization

- Soil stabilization is the treatment of natural soil to improve its engineering properties.
- Two categories:
  1. Mechanical - blending of different grades of soils to obtain a required grade
  2. Chemical - blending of the natural soil with chemical agents
- Commonly used agents are:
  - i. Portland cement,
  - ii. asphalt binders, and
  - iii. lime

Soil Stabilization

Soil Types and Stabilization Methods Best Suited for Specific Applications

Purpose	*Soil Type*	*Recommended Stabilization Methods*
1. Subgrade Stabilization		
A. Improved load-carrying and stress-distributing characteristics	Coarse granular	SA, SC, MB, C
	Fine granular	SA, SC, MB, C
	Clays of low PI	C, SC, CMS, LMS, SL
	Clays of high PI	SL, LMS
B. Reduce frost susceptibility	Fine granular	CMS, SA, SC, LF
	Clays of low PI	CMS, SC, SL, CW, LMS
C. Waterproof and improve runoff	Clays of low PI	CMS, SA, CW, LMS, SL
D. Control shrinkage and swell	Clays of low PI	CMS, SC, CW, C, LMS, SL
	Clays of high PI	SL
E. Reduce resiliency	Clays of high PI	SL, LMS
	Elastic silts and clays	SC, CMS
2. Base Course Stabilization		
A. Improve substandard materials	Fine granular	SC, SA, LF, MB
	Clays of low PI	SC, SL
B. Improve load-carrying and stress-distributing characteristics	Coarse granular	SA, SC, MB, LF
	Fine granular	SC, SA, LF, MB
C. Reduce pumping	Fine granular	SC, SA, LF, MB membranes
3. Shoulders (unsurfaced)		
A. Improve load-carrying ability	All soils	See section 1A above; also MB
B. Improve durability	All soils	See section 1A above
C. Waterproof and improve runoff	Plastic soils	CMS, SL, CW, LMS
D. Control shrinkage and swell	Plastic soils	See section 1E above
4. Dust Palliative	Fine granular	CMS, CL, SA, oil, or bituminous surface spray
	Plastic soils	CL, CMS, SL, LMS
5. Ditch Lining	Fine granular	PSC, CS, SA
	Plastic soils	PSC, CS
6. Patching and Reconstruction	Granular soils	SC, SA, LF, MB

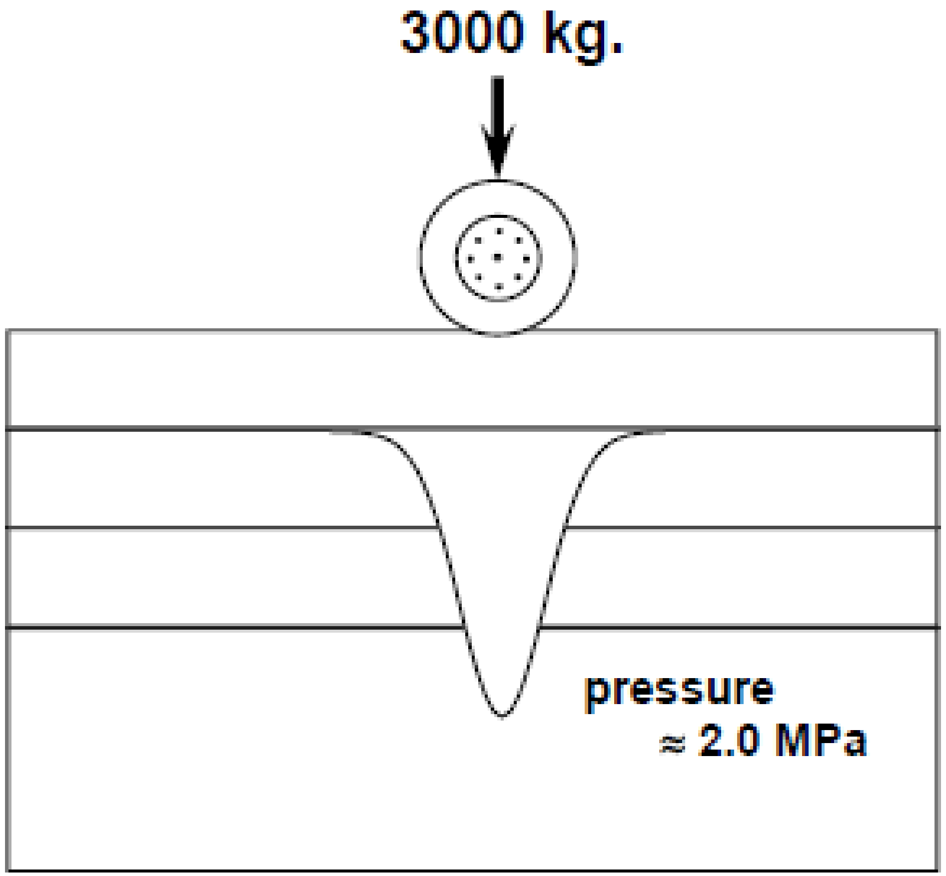
C = Compaction
CMS = Cement modified soil
CL = Chlorides
CS = Chemical solidifiers
CW = Chemical waterproofers
LF = Lime fly ash
LMS = Lime-modified soil
MB = Mechanical blending
PSC = Plastic soil cement
SA = Soil asphalt
SC = Soil cement
SL = Soil lime

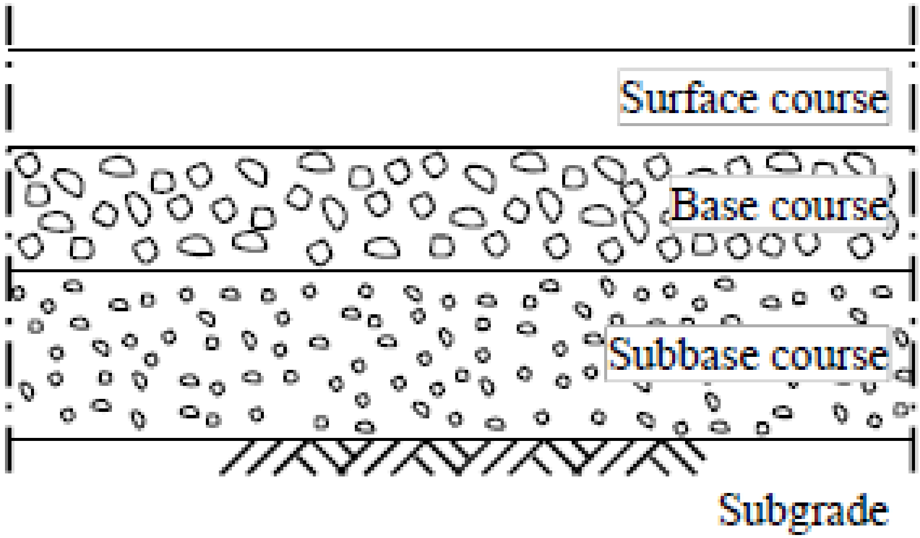
Soil Stabilization

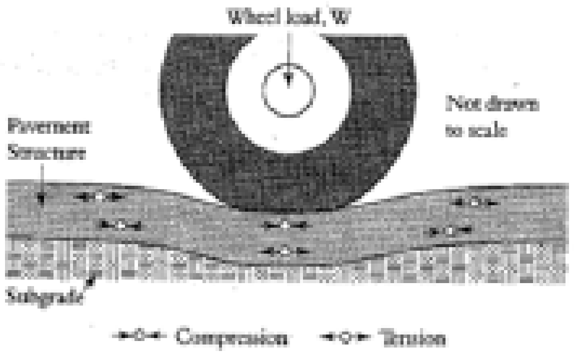
Normal Range of Cement Requirements

AASHTO Soil Group	Cement (percentage by weight of soil)	Cement (pounds per cubic foot of compacted soil cement)	Cement (kilograms per cubic meter of compacted soil cement)
A-1-a	3–5	5–7	80–110
A-1-b	5–8	7–8	110–130
A-2-4, A-2-5, A-2-6, A-2-7	5–9	7–9	110–140
A-3	7–11	8–11	130–180
A-4	7–12	8–11	130–180
A-5	8–13	8–11	130–180
A-6	9–15	9–13	140–210
A-7	10–16	9–13	140–210

Structural Components of a Flexible Pavement







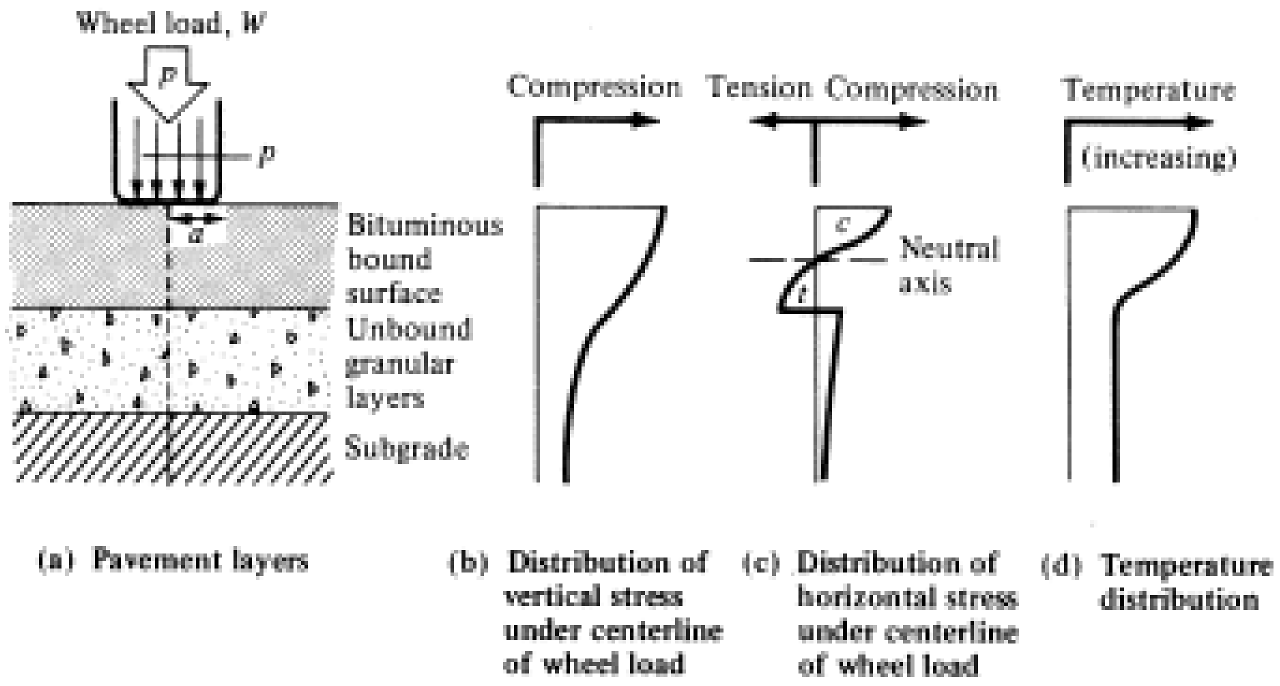
Structural Components of a Flexible Pavement

- Surface course (wearing surface):
  - The top layer of pavement directly in contact with traffic
  - A mixture of mineral aggregates and asphaltic materials
  - Main functions:
    - **Transmits the wheel loads to the underlying layers within acceptable limits**
    - **Resists abrasive forces due to traffic**
    - **Provides skid-resistant driving surface and reduces tractive resistance to traffic**
    - **Provides water and climatic protection to underlying layers**
- Base course:
  - Usually granular materials such as crushed stone, crushed or uncrushed gravel or slag, and sand
  - Strict specifications for plasticity, gradation, and strength
  - Can be stabilized using portland cement, asphalt, or lime when a higher strength is required or when the available materials do not meet the specifications
  - Main functions:
    - **Acts as a foundation to the surface course**
    - **Distributes the stresses on the subbase into a large area**
    - **Protects the surface course against volume changes that may take place in the subgrade**
    - **Prevents the effect of capillary rise**

Structural Components of a Flexible Pavement

- Subbase course:
  - A layer of granular materials that is located between the subgrade and base course
  - Quality of materials is superior to that of the subgrade but inferior to that of the base course
  - Can be omitted if the quality of the subgrade material meets the requirements of the subbase
  - Specifications are in terms of plasticity, gradation, and strength
  - Main functions:
    - **Reduces the stresses applied on the subgrade**
    - **Serves in water drainage**
    - **Protects the base course against volume changes of the subgrade**
    - **Prevents the rise of capillary water**
- Subgrade:
  - The natural material located along the horizontal alignment of the pavement
  - Serves as a foundation of the pavement structure

Structural Components of a Flexible Pavement



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

Stress Distribution within a Flexible Pavement

Design of Flexible Pavement

Design Methods of Flexible Pavement

Theoretical Method (Mechanistic)

- Boussinesq Theory (one – layer) (Stiffness Factor)

Empirical Method (Field Observations)

- Group Index (GI)
- Corps of Engineering (CBR method).
- National Crushed Stone Association (NCSA method) (CBR).
- AASHTO method

Empirical-Mechanistic Empirical-Theoretical

- Asphalt Institute method (AI method)

Design inputs:

Material Characterization, Traffic Characterization, Environment, and Failure Crierion ⟶ Design Method ⟶ Design Thickness

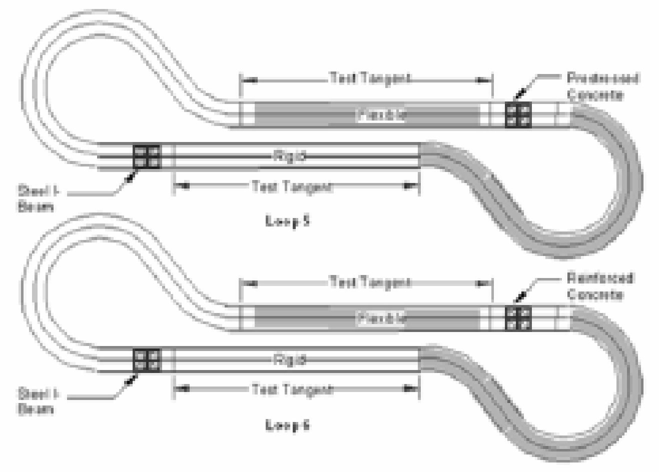
Design of Flexible Pavement

- In theoretical analysis, the pavement structure is usually considered a multilayered elastic system
- New analytical methods can model the plastic and viscous characteristics
- Pavement design should account not only to the stresses and strains resulting from load application but also to the fatigue resulting from load repetitions
- Objective: is to determine the minimum thickness of pavement layers that is enough to:
  - Avoid overloading or overstressing the subgrade
  - Avoid overloading or overstressing any one or more of the pavement layers
  - Maintain good serviceability performance along the pavement design life

Design of Flexible Pavement

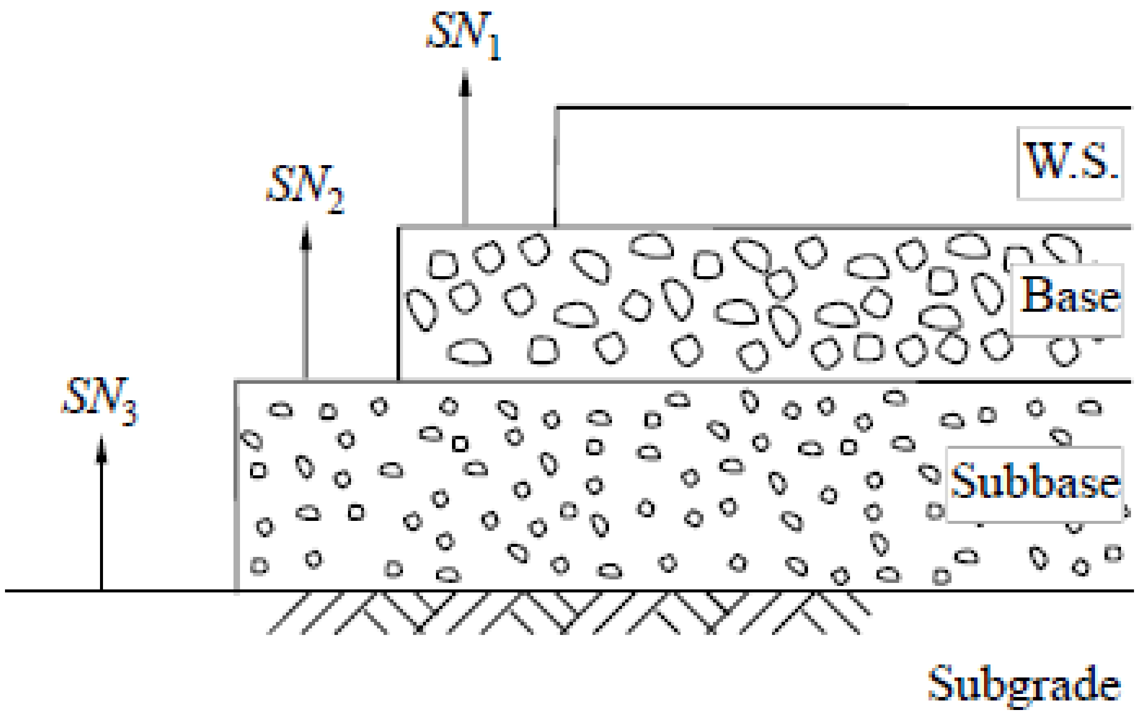
AASHTO Design Method

- Mainly empirical, based on the AASHO Road Test:
  - Test site was in Ottawa, Illinois
  - Straight portion of the track became part of I-80
  - Timeline:
    - **Construction: August 1956 - September 1958**
    - **Test Traffic: October 1958 - November 1960**
    - **Special Studies: Spring and early summer 1961**
  - Test facilities:
    - **Six 2-lane test loops**
    - **Loop 1 = not subject to traffic, used to test environmental effects**
    - **Loops 2 through 6 = subject to traffic**
    - **A total of 836 test sections including 16 short-span bridges**



Design of Flexible Pavement

- Pavement structure required on top of a specific layer is expressed in terms of Structural Number (SN)



Design of Flexible Pavement

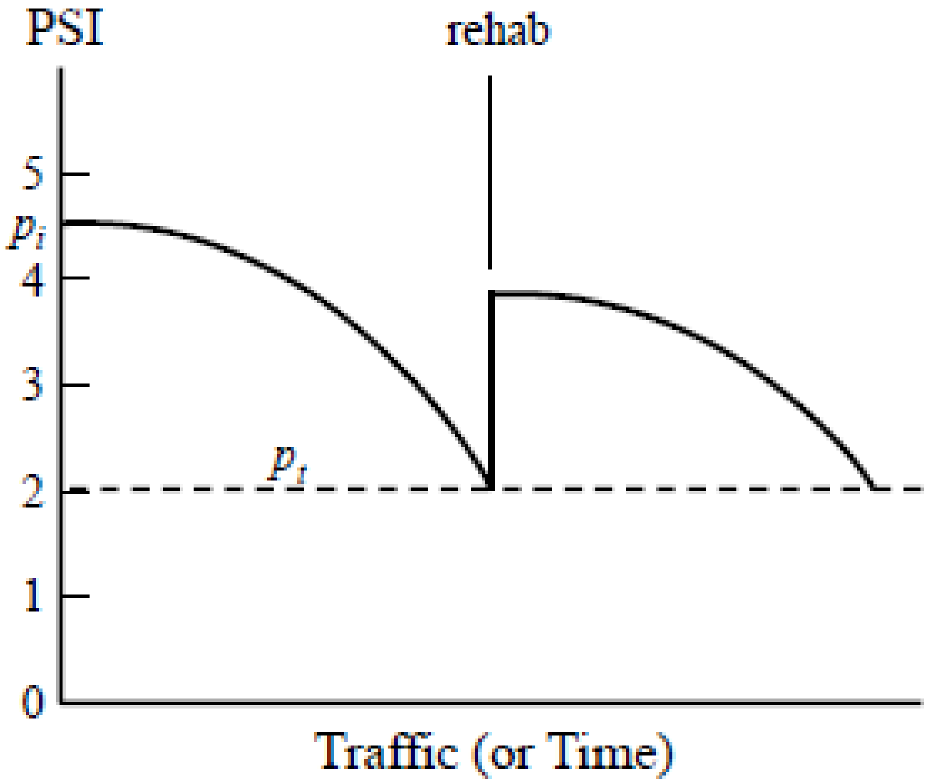
❖ The factors considered in the AASHTO procedure for the design of flexible pavement as presented in the 1993 guide are:

- Pavement performance
- Traffic
- Roadbed soils (subgrade material)
- Materials of construction
- Environment
- Drainage
- Reliability

Design of Flexible Pavement

Pavement Performance:

- Structural and functional performance
- Present Serviceability Index (PSI):
  - Quantifies pavement performance based on its roughness and distress
  - Ranges from 0 (lowest) to 5 (highest)
  - Immediately after construction
    - p_i = 4.2 to 4.5
  - At the end of the pavement design life:
    - p_t =
      - *2.5 to 3.0 for major highways*
      - *2.0 for highways with lower classification*



Design of Flexible Pavement

Traffic:

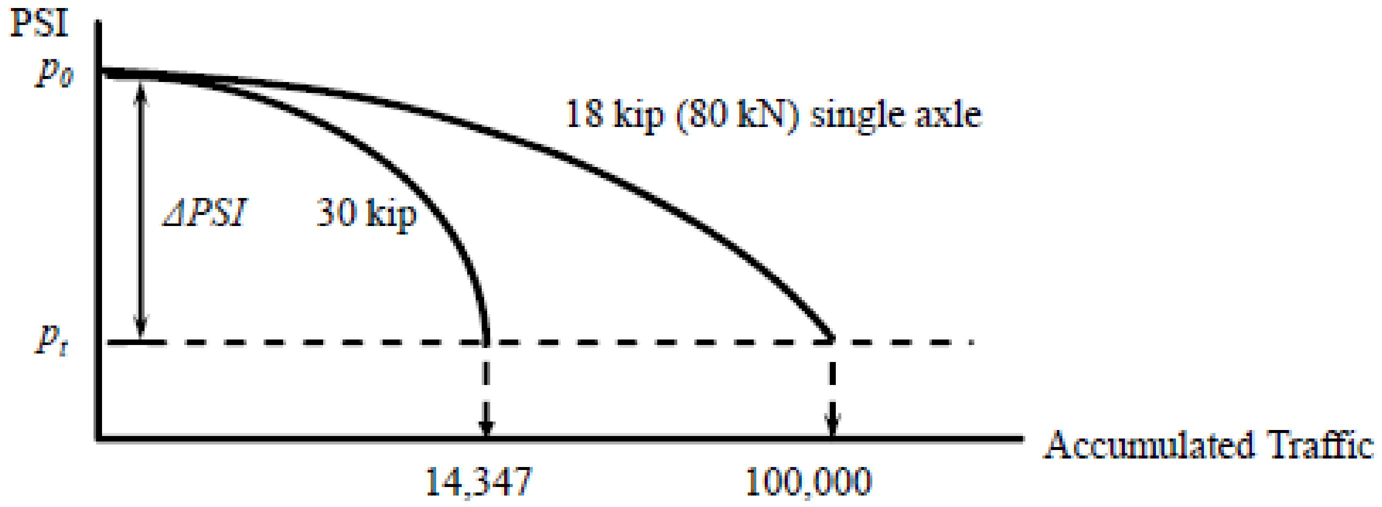
- Traffic input
  - AADT
  - Percentage of commercial vehicles
- Sources of data
  - Regional traffic office
  - Commercial vehicle surveys (CVS)
  - Weigh-in-motion (WIM) stations
  - Vehicle inspection stations (shorter scales)
- Traffic Loads are expressed in terms of the number of repetitions of an 18 kips single-axle load, referred to as Equivalent Single Axle Load (ESAL)

Design of Flexible Pavement

- Load equivalency factors (LEF):
  - In general::

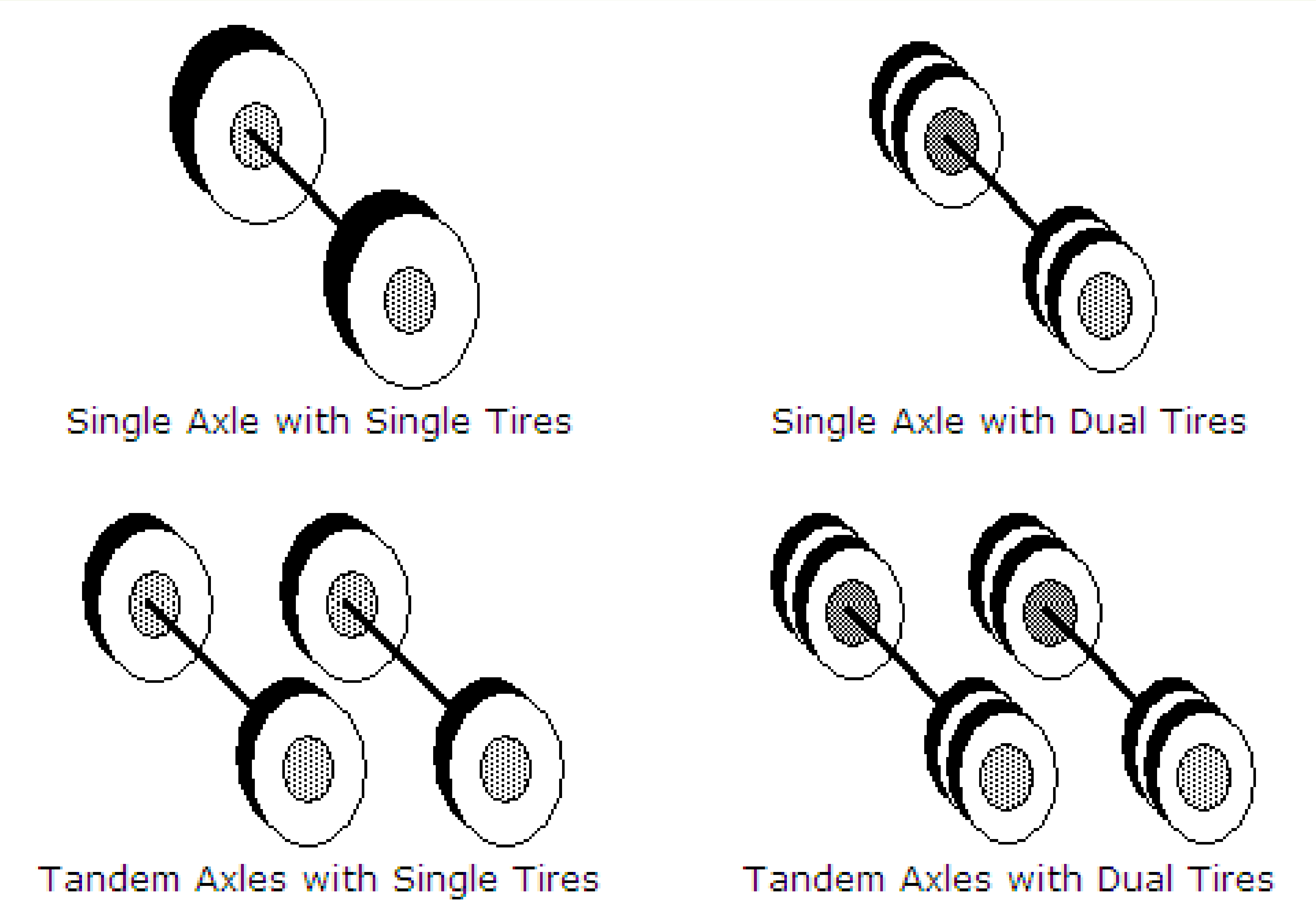
$$\text{LEF} = \frac{\text{No. of 18 kip ESAL to cause loss of serviceability}}{\text{No. of X kip axle loads to cause same loss}}$$

  - Example:
    - **100,000 reps of a 18 kip (SAL)**
    - **14,347 reps of a 30 kip load (SAL)**



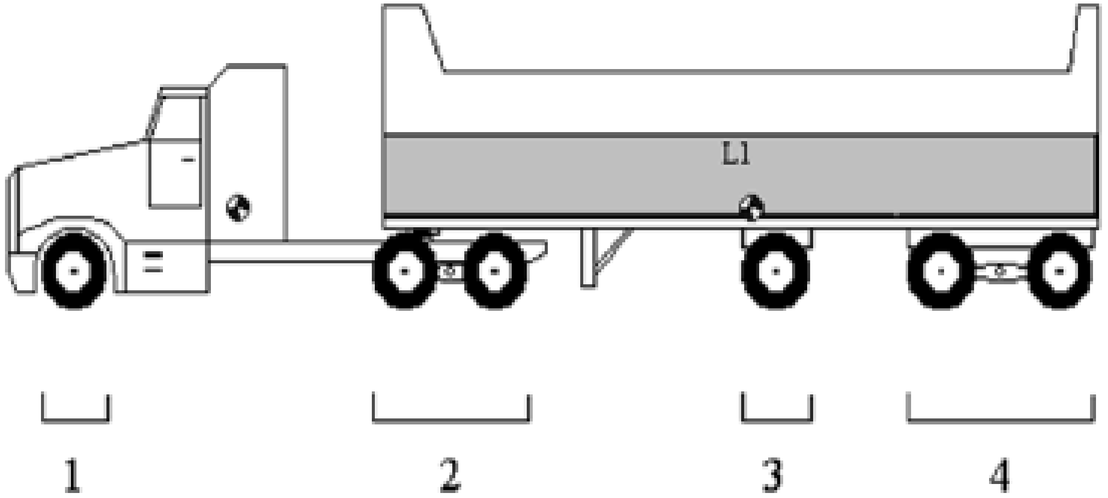
- **LEF 30–kip SAL**$= \frac{100,000}{14,347} = 6.97$

- Equivalency factors for single and tandem axles are available based on SN


Single Axle with Single Tires
Single Axle with Dual Tires
Tandem Axles with Single Tires
Tandem Axles with Dual Tires

Design of Flexible Pavement

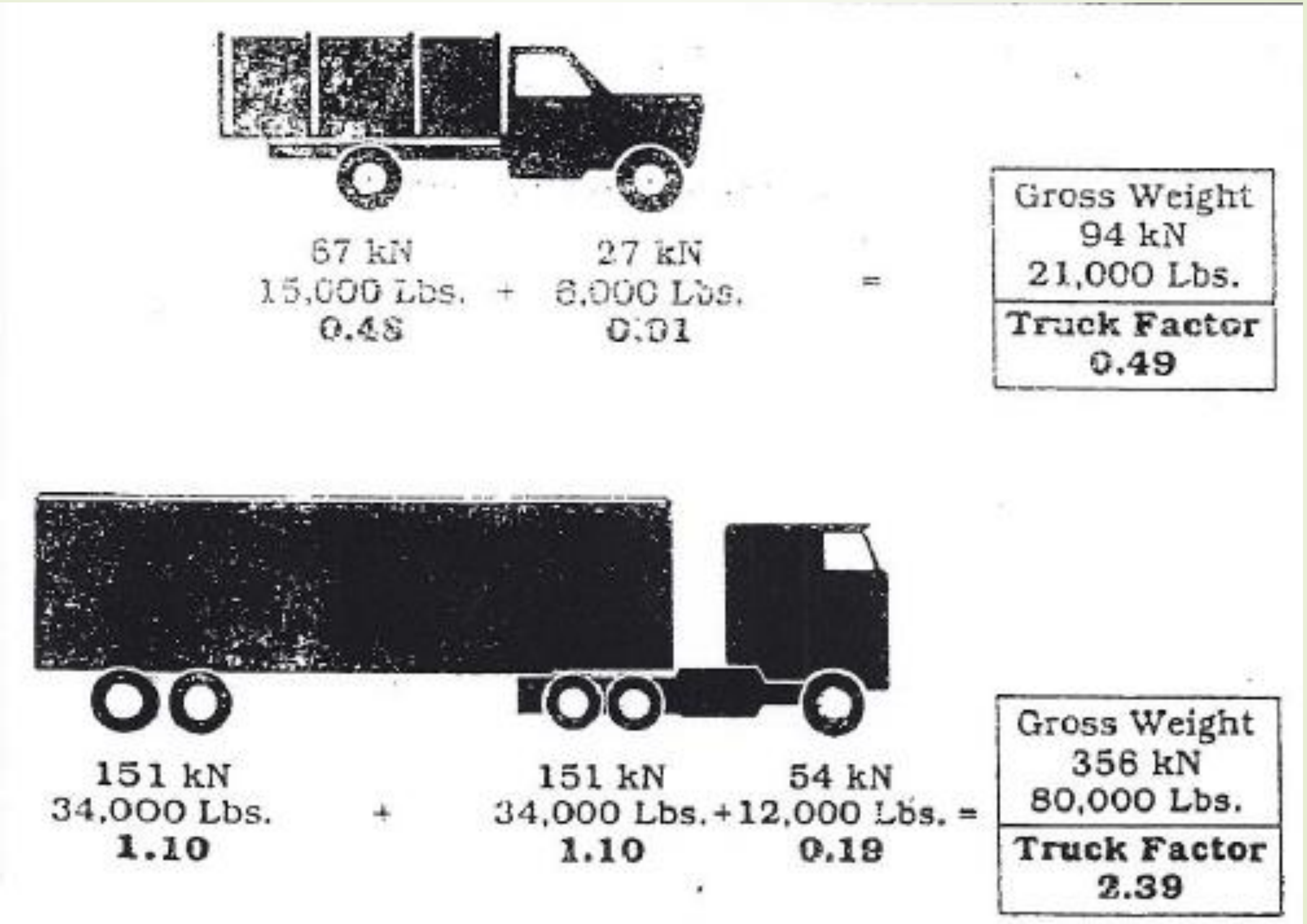
- Truck Factor (TF) can be calculated as the ESAL for a specific truck category
  - TF = Sum of LEFs for all the axles



LEF [0.31] [3.45] [1.94] [1.727]

- TF = 0.31+3.45+1.94+1.727 = 8.35

Design of Flexible Pavement



Some Typical Load Equivalency Factors

Axle Type (lbs)	Axle Load		Load Equivalency Factor (from AASHTO, 1993)	
	(kN)	(lbs)	Flexible	Rigid
Single axle	8.9 44.5 62.3 80.0 89.0 133.4	2,000 10,000 14,000 18,000 20,000 30,000	0.0003 0.118 0.399 1.000 1.4 7.9	0.0002 0.082 0.341 1.000 1.57 8.28
Tandem axle	8.9 44.5 62.3 80.0 89.0 133.4 151.2 177.9 222.4	2,000 10,000 14,000 18,000 20,000 30,000 34,000 40,000 50,000	0.0001 0.011 0.042 0.109 0.162 0.703 1.11 2.06 5.03	0.0001 0.013 0.048 0.133 0.206 1.14 1.92 3.74 9.07

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

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

Design of Flexible Pavement

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

Design of Flexible Pavement

$$ESAL_i = f_d \times G_{rn} \times AADT_i \times 365 \times N_i \times F_{Ei}$$

where

$ESAL_i$ = 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

Note: When using Truck Factor, drop Ni from this equation

Design of Flexible Pavement

$$\boxed{\Sigma ESAL = W_{18} = ADT * T * TF_a * 365 * DD * LD * G}$$

$$\underset{\text{Design Traffic}}{W_{18}} = \underbrace{\underset{\text{Average Daily Traffic}}{ADT} \times \underset{\text{\% Trucks}}{T} \times \underset{\text{Truck Factor}}{TF}}_{\text{EAL (Daily)}} \times 365 \times \underset{\text{Directional Distribution}}{DD} \times \underset{\text{Lane Distribution}}{LD} \times \underset{\text{Growth Factor}}{G}$$

Design of Flexible Pavement

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

where

$r = \dfrac{i}{100}$ and is not zero. If annual growth is zero, growth factor = design period

i = growth rate

n = design life, yrs

Design of Flexible Pavement

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

Design of Flexible Pavement

Example – Calculating ESAL

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.

Design of Flexible Pavement

Vehicle Class	Parameters for Calculating ESAL						$ESAL_i$
	f_d	G_{rn}	%	$AADT_i$	N_i	F_{EI}	
Passeger Car	0.45	29.78	50%	6000	2	0.0002	1.174E+04
2-Axle Single Unit Trucks	0.45	29.78	33%	3960	2	0.1	3.874E+06
3-Axle Single Unit Trucks	0.45	29.78	17%	2040	3	0.88	2.634E+07
Total ESAL							**3.0227E+07**

Design of Flexible Pavement

Example – Calculating ESAL Using Truck Factor

Design Life	25	years				
Design Lane Factor, fd (Directional Distribution)	45%					
Growth Rate	7%					
AADT	4000	vpd				
Vehicle Class	Parameters for Calculating ESAL					$ESAL_i$
	f_d	G_{rn}	%	$AADT_i$	TF	
Truck	0.45	63.25	30%	1200	0.45	5.610E+06
Total ESAL						**5.61E+06**

Design of Flexible Pavement

Road Soils (Subgrade):

- Subgrade strength is expressed in terms of resilient modulus (M_r)
- If only CBR is known:
  - M_r = 1500 CBR (fine grained soils, CBR $\leq$ 10)

Materials of Construction:

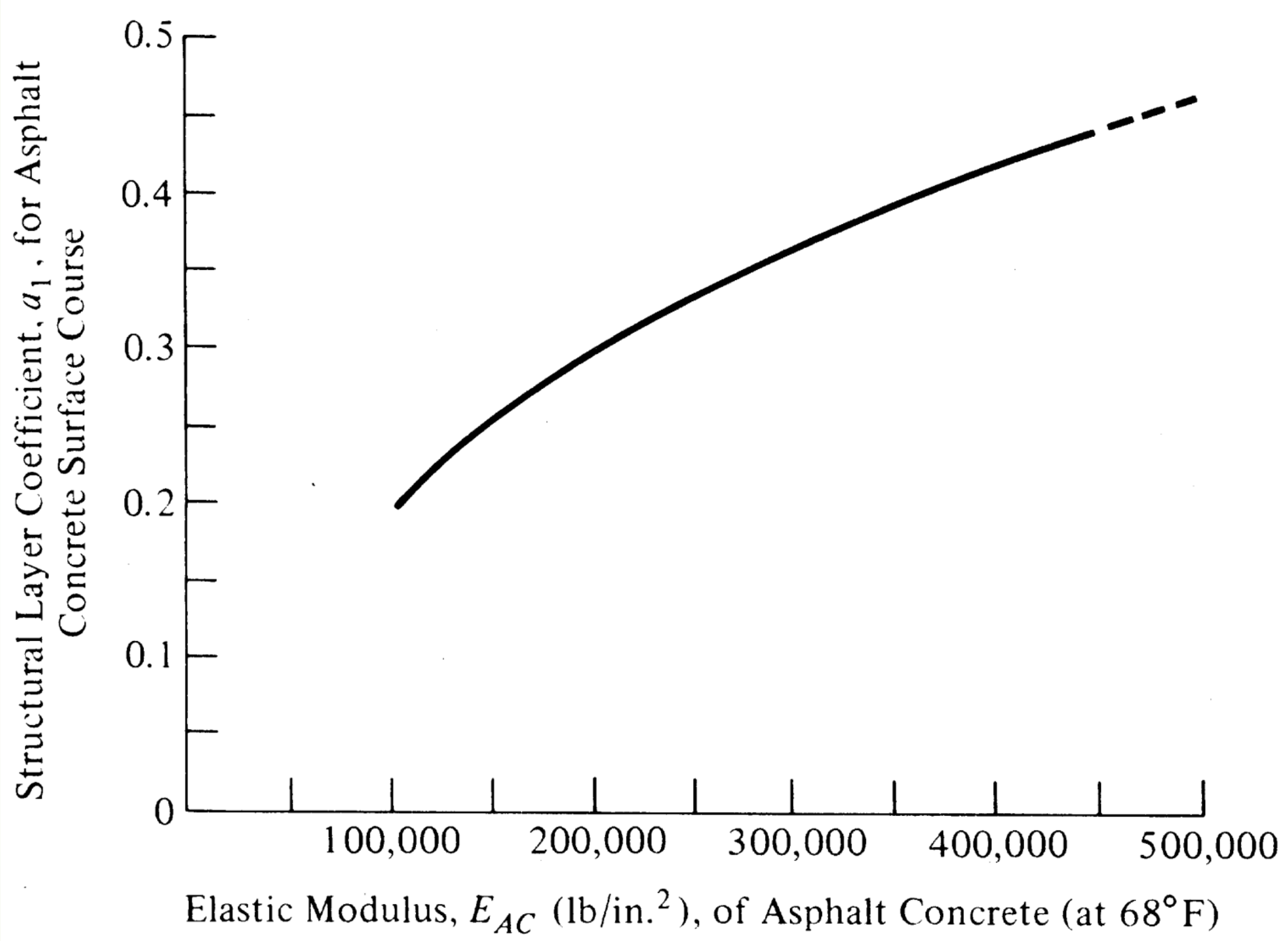
- Quality of materials of pavement layers is determined using layer coefficient a_i
- a_3, a_2, and a_1 for subbase, base, and wearing surface

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 $R \leq 20$)

Design of Flexible Pavement

- Resilience Modulus



Design of Flexible Pavement

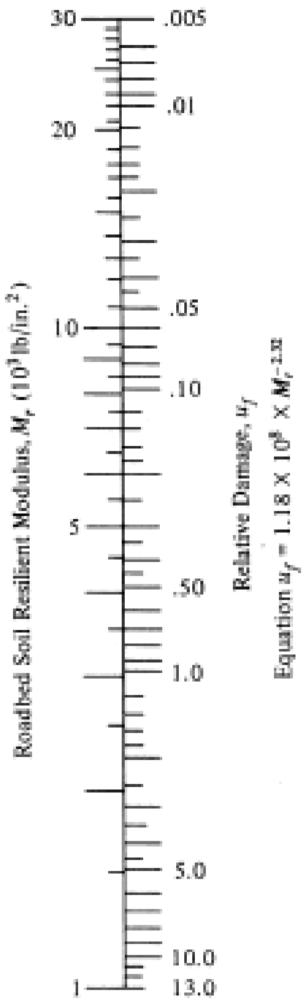
Environment:

- Effect of varying M_r due to varying water content during a specific period is considered by determining an effective M_r for this period
- To determine an effective M_r within a period:
  - For each sub-period, determine the relative damage, u_f, corresponding to the period's M_r
  - Determine the mean relative damage, u_f
  - Determine the effective M_r corresponding to u_f

Design of Flexible Pavement

- Construction Materials

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}) = 7250 (corresponds to $\bar{u}_f$)

Chart for Estimating Effective Roadbed Soil Resilient Modulus for Flexible Pavements Designed Using the Serviceability Criteria

Design of Flexible Pavement

Drainage:

- The effect of drainage on the pavement performance is considered by incorporating a factor (m_i) for the base and subbase layer coefficients (a_2 and a_3)

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: Based on *AASHTO Guide for Design of Pavement Structures*, 1993, AASHTO, Washington, D.C.

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

SOURCE: Based on *AASHTO Guide for Design of Pavement Structures*, 1993, AASHTO, Washington, D.C.

Design of Flexible Pavement

Reliability:

- Reliability design level, R, is introduced to account for uncertainties in traffic and performance predictions
- Overall standard deviation, S_0, for flexible pavements = 0.4 – 0.5

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: Based on *AASHTO Guide for Design of Pavement Structures*, 1993, AASHTO, Washington, D.C.

Design of Flexible Pavement

Structural Design

Objective:

- To determine the minimum thickness of wearing surface, base, and subbase (D_1, D_2, and D_3)

Procedure:

- Determine the total ESAL for the design period
- Determine the design serviceability loss = $\Delta PSI = p_i - p_t$
- Determine the effective M_r (subgrade), M_r for base and subbase, and layer coefficients (a_1, a_2 & a_3)
- Determine the drainage coefficients (m_2 & m_3)
- Select the reliability design level (R) and overall standard deviation (S_0)
- Use M_r of the base to determine SN_1
  - $SN_1 = a_1 D_1 \Rightarrow$ get D_1
  - Check minimum value and determine design value D_1^*
- Use M_r of the subbase to determine SN_2
  - $SN_2 = a_1 D_1^* + a_2 D_2 m_2 \Rightarrow$ get D_2
  - Check minimum value (Table 19.11) and determine design value D_2^*
- Use M_r of the subgrade to determine SN_3
  - $SN_3 = a_1 D_1^* + a_2 D_2^* m_2 + a_3 D_3 m_3 \Rightarrow$ get D_3
  - Determine design value D_3^*

Design of Flexible Pavement

where

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

The basic design equation given in the 1993 guide is

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

where

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

ΔPSI = $p_i - p_t$

Design of Flexible Pavement

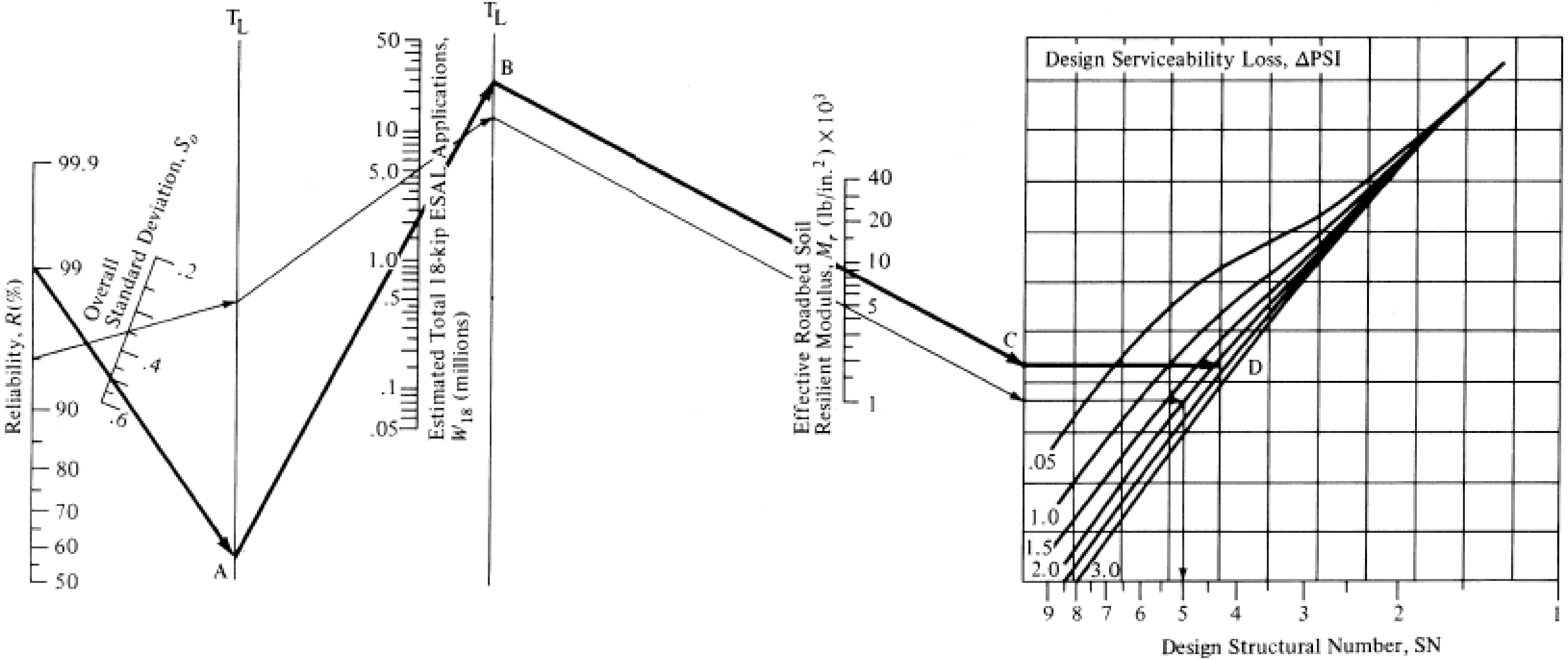
p_i = initial serviceability index
p_t = terminal serviceability index
M_r = resilient modulus (lb/in^2)

Design of Flexible Pavement

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

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



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

AASHTO-Recommended Minimum Thicknesses of Highway Layers

Traffic, ESALs	*Minimum Thickness (in.)*	
	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: Based on *AASHTO Guide for Design of Pavement Structures*, 1993, AASHTO, Washington, D.C.

Design of Flexible Pavement

[Example - Structural Design of Flexible Pavements (Click to see example)]

Thank You!!!