Pavement Design

What is Pavement?

- Pavement is the upper part of roadway, airport or parking area structure
- It includes all layers resting on the original ground
- It consists of all structural elements or layers, including shoulders

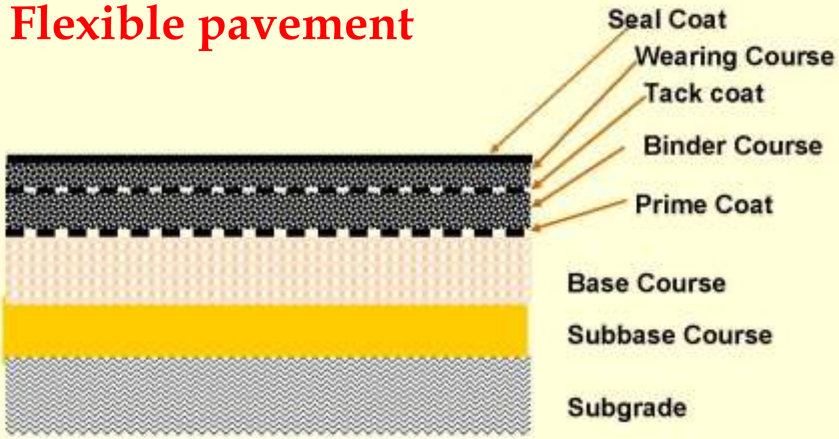
What is a pavement design?

- It is the process by which the structural components of a road segment are determined taking into account the nature of the subgrade, density and traffic composition

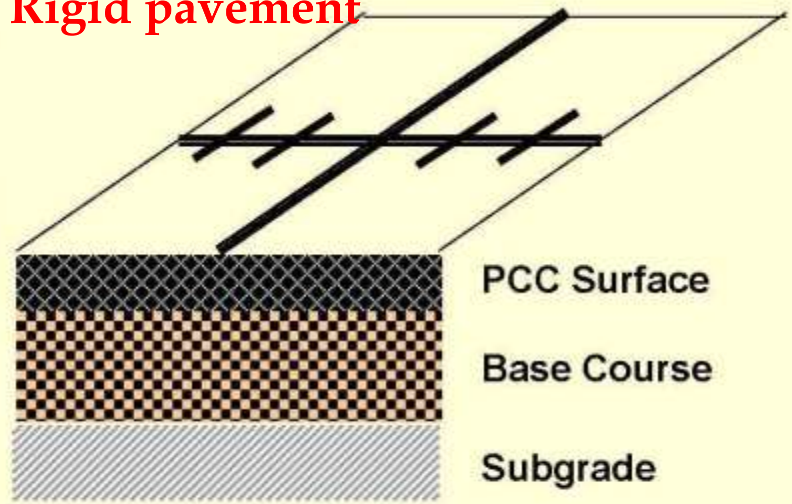
Pavement Performance

Types of pavements

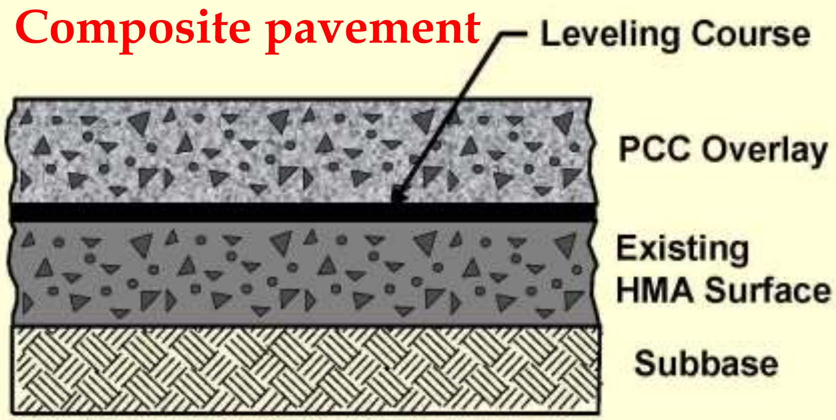
Flexible pavement



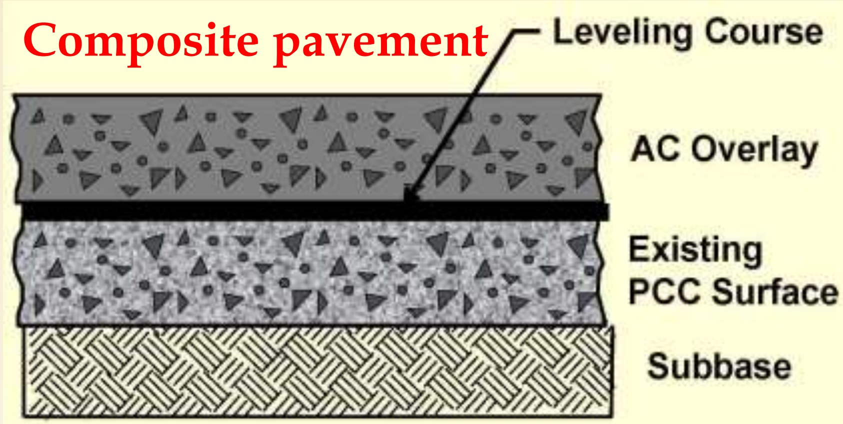
Rigid pavement



Composite pavement



Composite pavement



Pavement Performance

Functions of the Pavement Structure

- Reduce and distribute the traffic loading so as not to damage the subgrade
- Provide vehicle access between two points under all-weather conditions
- Provide safe, smooth and comfortable ride to road users without undue delays and excessive wear & tear
- Meet environmental and aesthetics requirements
- Limited noise and air pollution
- Reasonable economic

Pavement Performance

Pavement Design Phases

Highway design consists of three stages

- Geometric design (route selection or alignment design)
- Capacity design (number of lanes to meet traffic demand)
- Structural design to withstand loads and environment

Structural design consists of 3 steps

- Selection of materials (types of pavement)
- Proportioning of materials
- Layer thickness design

Pavement Performance

Requirements of pavement structure

- Sufficient thickness to spread loading to a pressure intensity tolerable by subgrade
- Sufficiently strong to carry imposed stress due to traffic load

a1(a1>0)=1;

- Sufficient thickness to prevent the effect of frost susceptible subgrade
- Pavement material should be impervious to penetration of surface water which could weaken subgrade and subsequently pavement
- Pavement materials should be non-frost susceptible
- Pavement surface should be skid resistant

Pavement Serviceability

Pavement Serviceability

Pavement serviceability can be briefly defined as the ability of a pavement section to serve traffic in its current condition

Two methods are used to measure pavement serviceability:

- **Present serviceability index (PSI):** roughness + distress characteristics
- **Roughness:** surface characteristics of pavements

Pavement Serviceability

Present Serviceability Index (PSI)

- Pavement serviceability index correlates subjective rating of a section with field measurements covering both roughness and distresses
- Rating of serviceability of a section between 0 for poor and 5 for excellent

Scales used for PSI

Material Characterization

Pavement materials characterization tests

- ***Characterization tests for <u>unbound layers</u> (subgrade, subbase and base courses)***
  - **Resilient Modulus**
    - Represents the stiffness of a soil under the repeated load application.
    - It can be calculated as the ratio of axial stress to the recoverable strain:

$$M_R = \frac{\sigma_d}{\varepsilon_r}$$

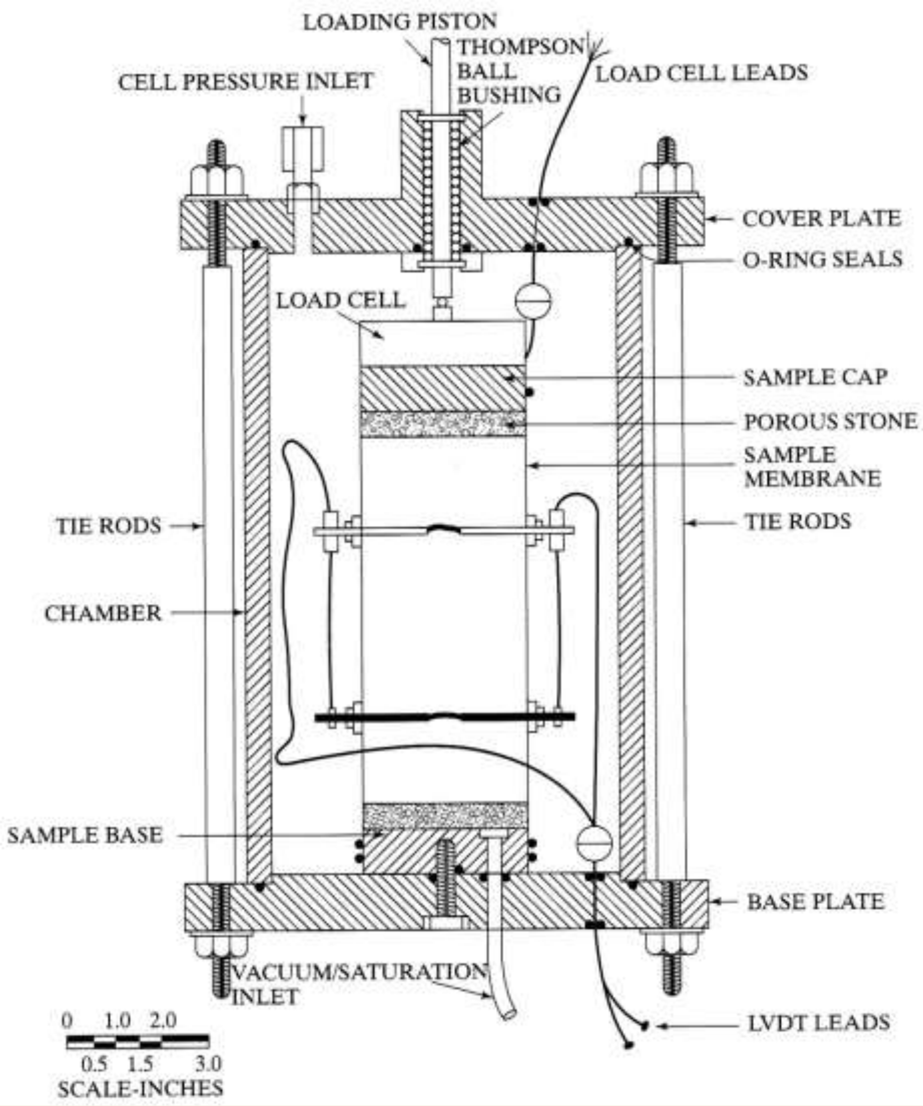
where σ_d : deviatoric stress;

ε_r : recoverable strain

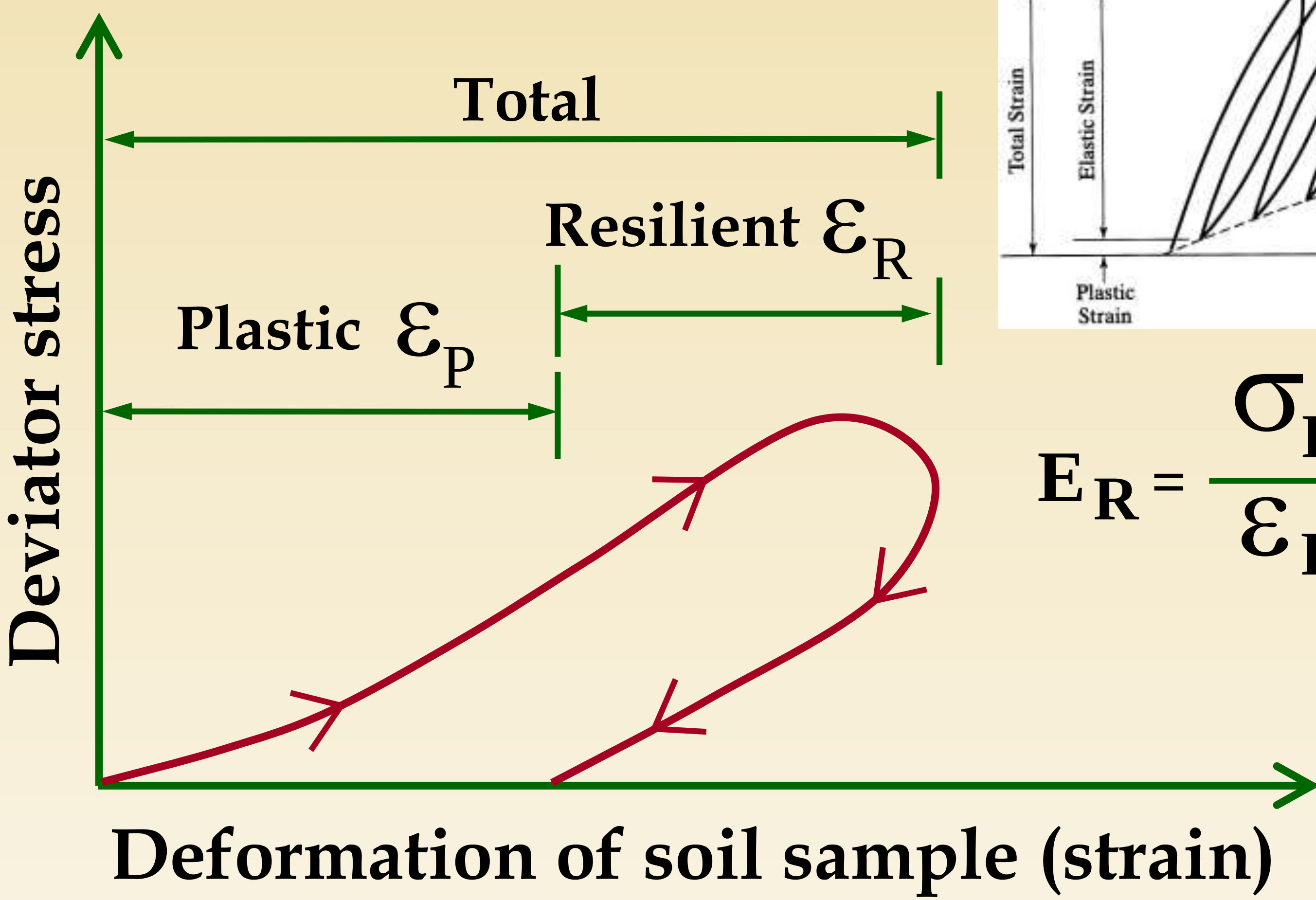
    - Repeated haversine loading is used to represent the traffic loading

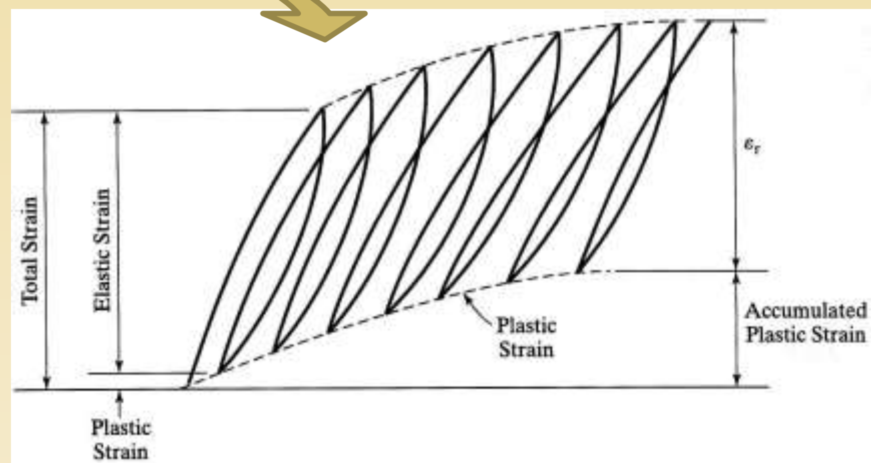
Material Characterization

- **Resilient modulus test setup**
- Stress-strain relationship is derived by applying a repeated deviatoric stress and recoding recoverable strain
- AASHTO T307 and NCHRP 1-28A are the current test procedures used



Material Characterization

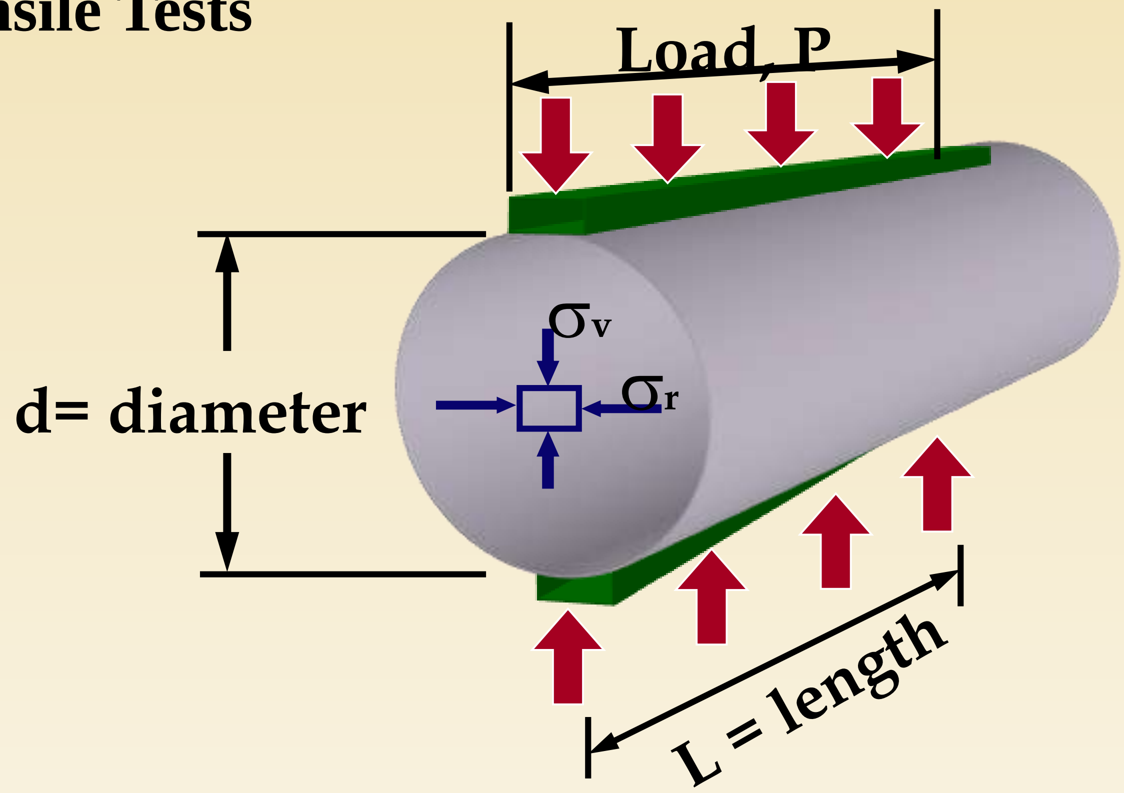




$$E_R = \frac{\sigma_D}{\varepsilon_R}$$

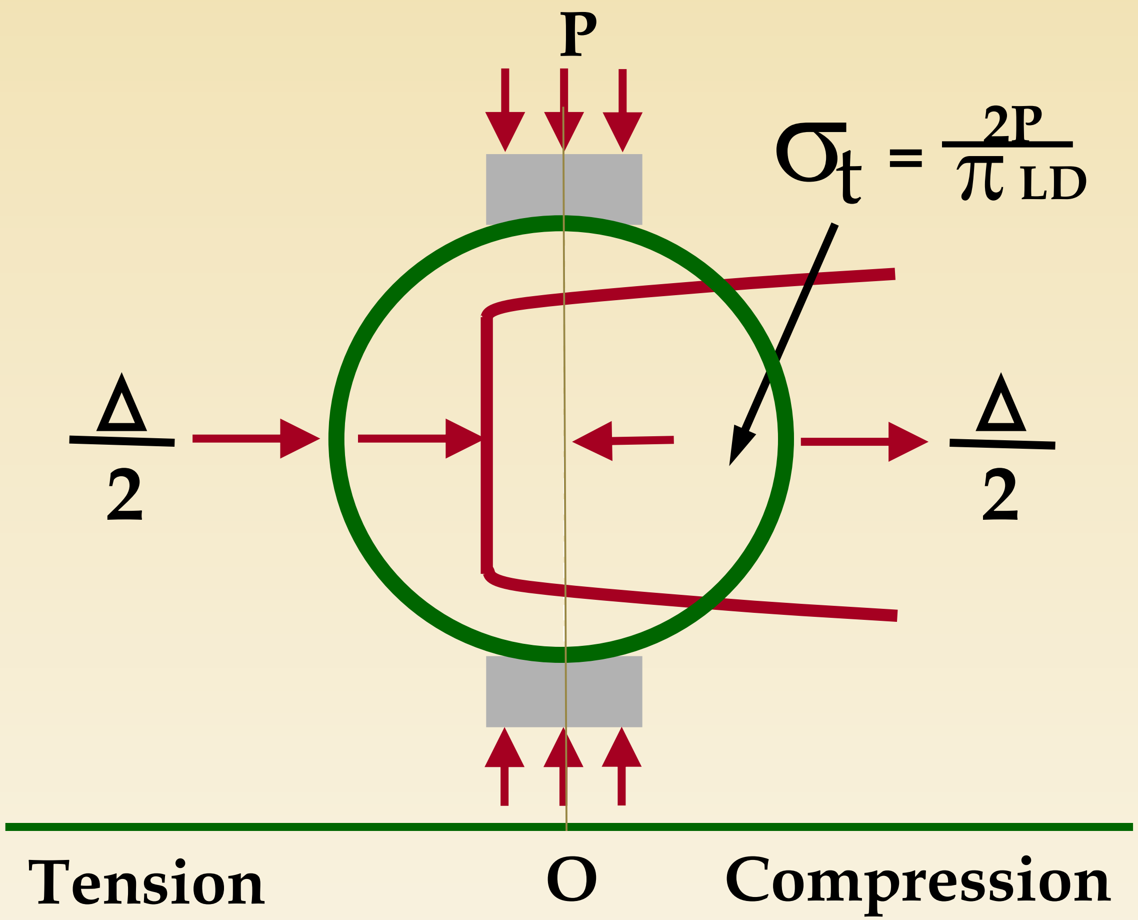
Material Characterization

- ***Characterization tests for <u>bound layers</u> (wearing course and binder course)***
  - **Indirect Tensile Tests**



Material Characterization

- **Indirect Tensile Tests**



Traffic Analysis

Traffic Analysis

Equivalent Axle Load Factor:

- The equivalent axle load factor (EALF) gives a relation between an induced *damage* by per pass of a specific axle configuration relative to the *damage* by per pass of a single axle.
- The design is carried out using the number of passes of the standard axle load, which is taken as 18 kip or 80 kN and called **ESAL** (equivalent single axle load)

$$EASL = \sum_{i=1}^{m} F_i n_i$$

where *m* the number of axle groups; F_i EALF for the *i*-th axle group; and n_i the number of passes of the *i*-th axle group during the design period

Traffic Analysis

Definitions Used in traffic Analysis:

- ESAL: Unit of measure in pavement design equivalent to the damage caused by the passing of a single 80 kN axle
- Load equivalency factor (LEF): The equivalent number of 80 kN ESALs for a specific combination of pavement type (flexible or rigid), terminal serviceability, axle type, and axle weight
- Truck factor (TF): The equivalent number of 80 kN ESALs for a specific combination of truck axle configuration, gross vehicle weight, pavement type (flexible or rigid), and pavement terminal serviceability

Traffic Analysis

Equivalent Single Axle Load (ESAL):

- Lane Distribution factor (LD): Truck distribution in the lanes of the design highway
- Directional distribution (DD): the percent of truck traffic traveling in one direction
- Weigh-in-motion (WIM): A technique of weighing vehicles while in motion. The process uses any one of a number of different technologies to weigh vehicles
- Automatic vehicle classification (AVC): Any one of several technologies which are capable of counting and classifying vehicles by axle spacing and axle grouping.
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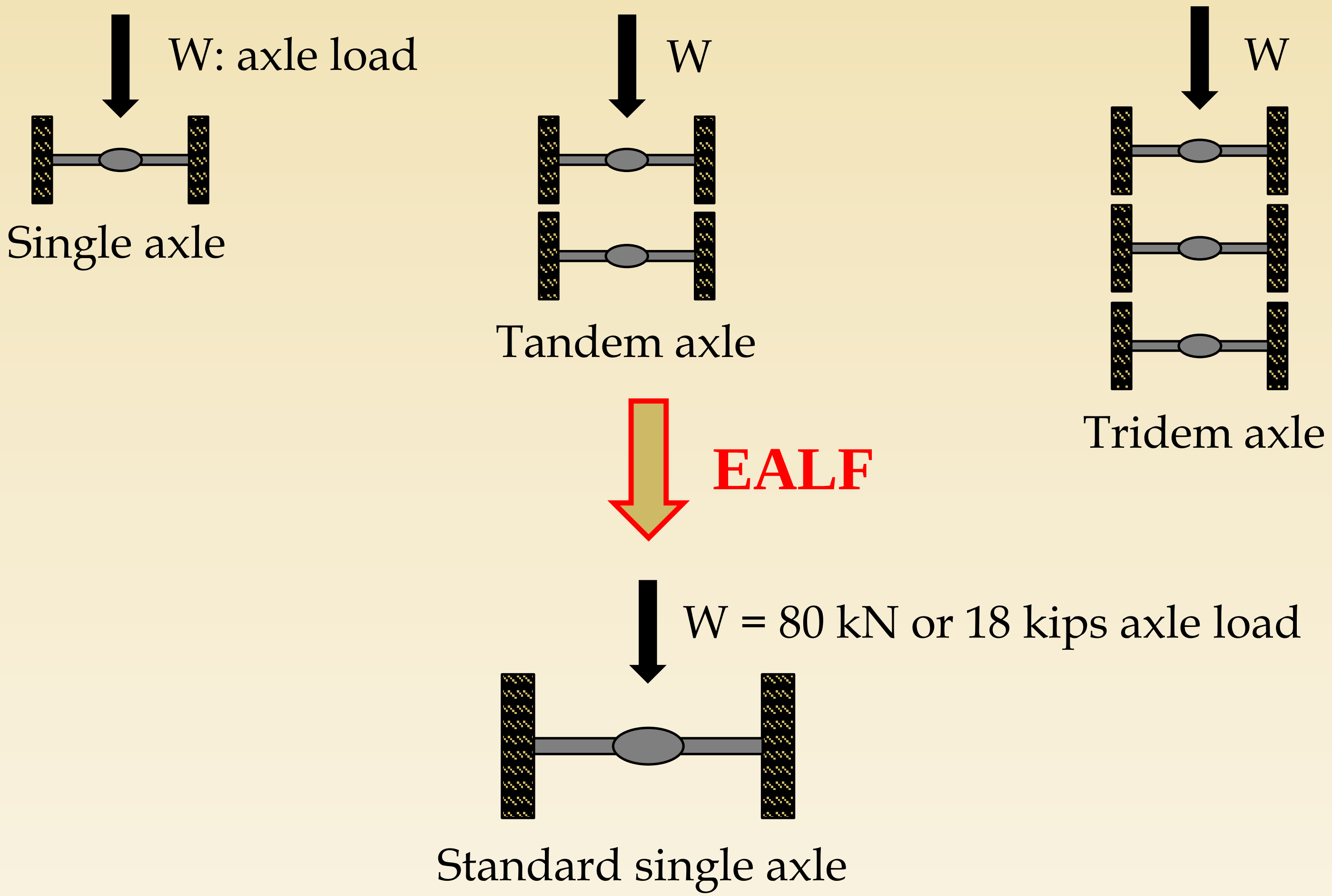
Traffic Analysis

Calculation of EALF



Traffic Analysis

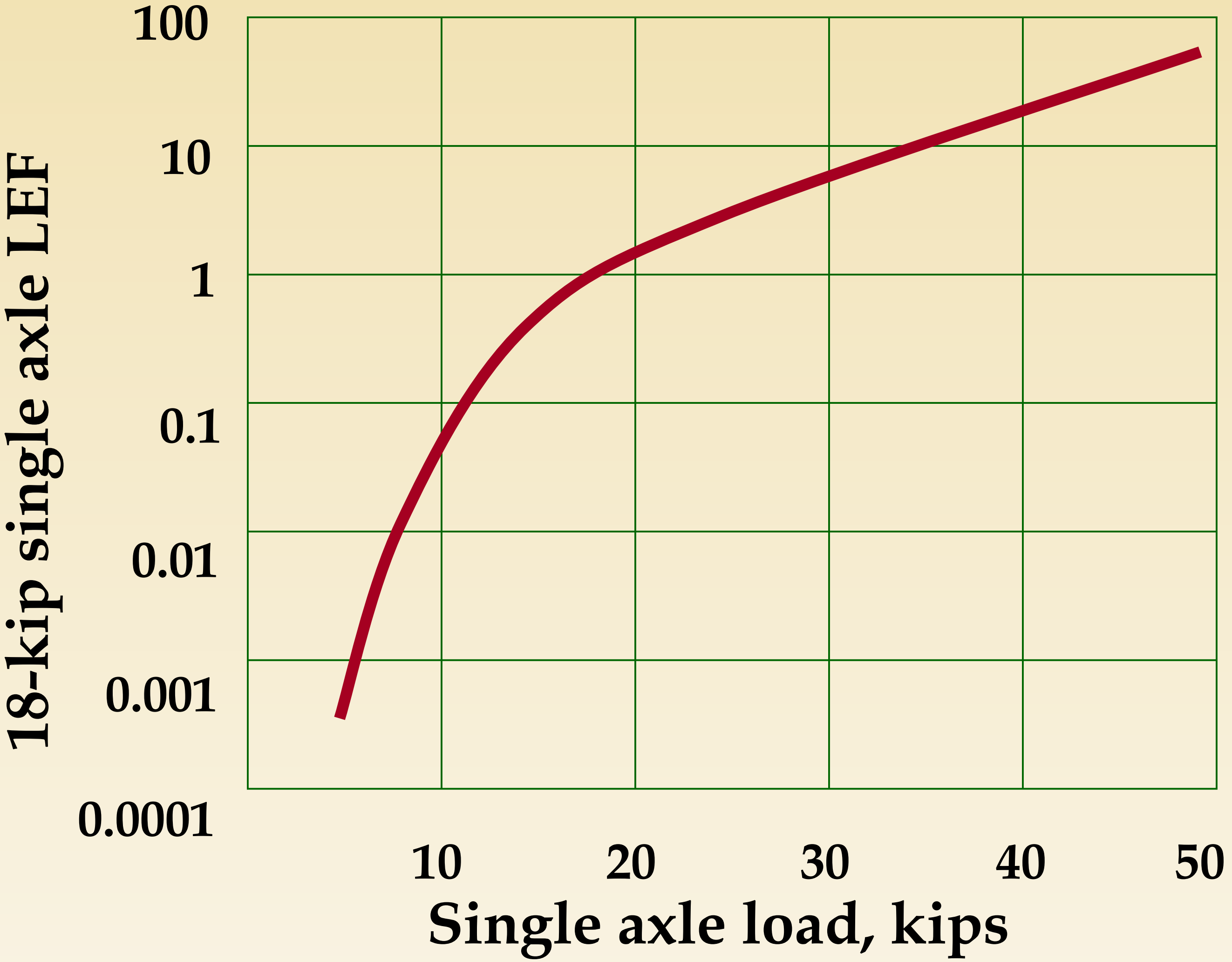
Equivalent Axle Load Factor:

Table D.4. 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.	102.	79.	60.	53.	55.

Traffic Analysis

Effect of Relative Damage by each LEF:



Traffic Analysis

Measuring Axle Load in the Field:

Types of WIM devices

- Bridge weighing devices
- Capacitance pads
- Piezoelectric cables
- Strain gauge load cells
- Strain gauge bending plates
- Hydraulic load cells

Traffic Analysis

Calculating EASL for a Design Section:

ESAL = ADT x TKS x DD x LD x TF x 365

where

ESAL =Number of 80 kN ESAL applications in design lane for 1 year

ADT =Initial two-way average daily traffic, vehicles per day

TKS =Percent of ADT that is heavy trucks (FHWA class 5 or greater)

DD =Directional distribution of truck traffic (decimal, not percent)

LD =Lane distribution of trucks in design lane (decimal, not percent)

TF =Average truck factor for all trucks, ESALs per truck

Flexible Pavement Design AASHTO 1993

AASHTO 1993 flexible pavement design process include two main steps:

- **DESIGN REQUIREMENTS**
- **DESIGN PROCESS**

Design variables: include four main inputs:

- **Time constraints**
- **Traffic**
- **Reliability**
- **Environmental effects**
- **Material properties**

Flexible Pavement Design AASHTO 1993

Design variables

- **Time constraints**
  - **Performance period:** the amount of time that the pavement will serve without any rehabilitation or time between rehabilitation periods
  - **Analysis period:** the amount of time the design process is carried out

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

Typical analysis periods for various road types

Flexible Pavement Design
AASHTO 1993

Design variables

- **Traffic:** the cumulative expected 80 kN equivalent single axle load on the design lane. The two directional traffic can be reduced to design lane using the following formula:

$$w_{80} = D_D \, x \, D_L \, x \, \widehat{w}_{80}$$

w_{80} : traffic in the design lane; D_D : directional distribution
D_L : lane distribution; $\widehat{w}_{80}$: cumulative two-directional traffic

- **Reliability:** introducing certain level of uncertainty to the design to ensure that the various design alternatives will last the analysis period

Flexible Pavement Design AASHTO 1993

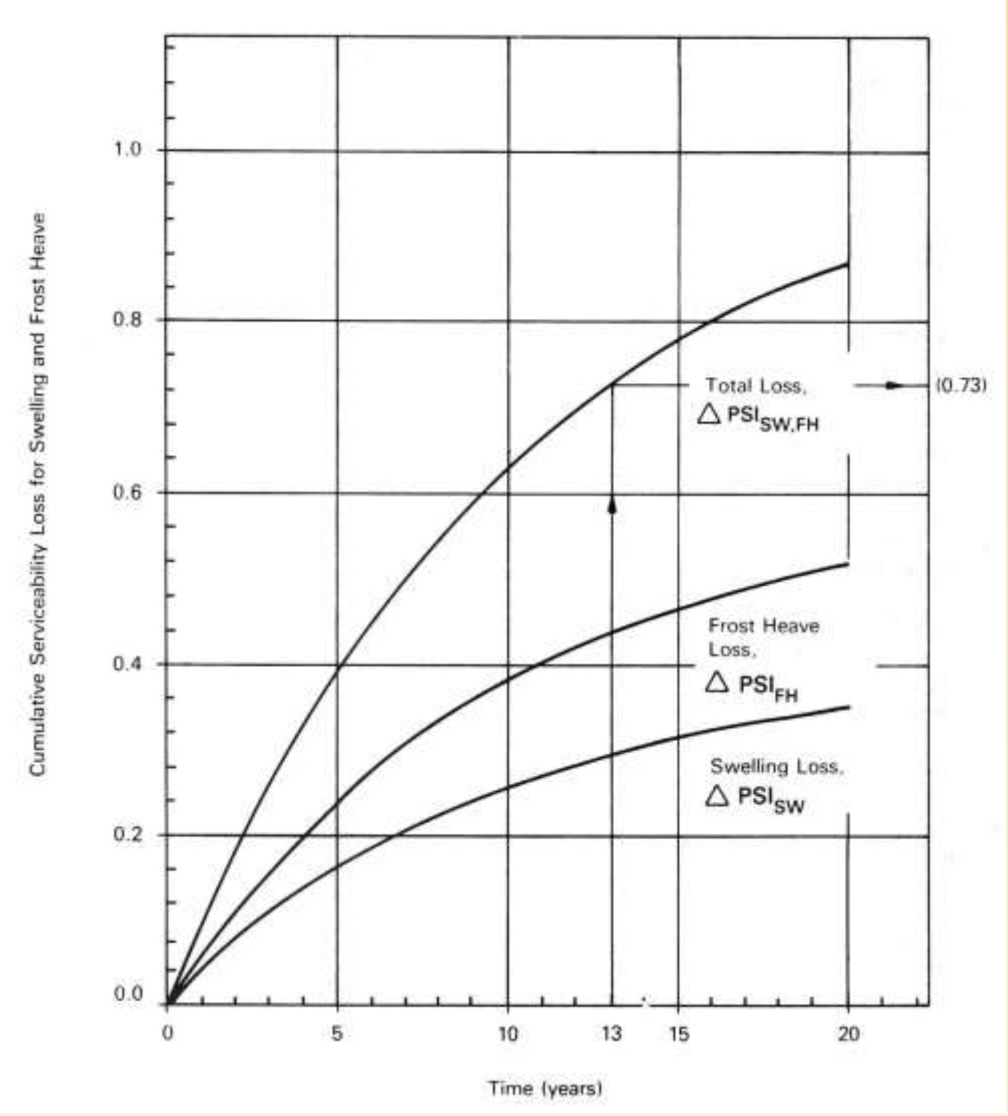
Environmental effects: effect of environmental factors on design causing loss of serviceability

- ***Serviceability loss due to frost heave***

$$\Delta PSI_{FH} = 0.01 P_D \Delta PSI_{FH_{max}} \left[1 - e^{-(0.02\emptyset t}\right]$$

- ***Serviceability loss due to swelling***

$$\Delta PSI_{SW} = 0.00335 V_R P_{SW} \left[1 - e^{-\emptyset t}\right]$$



Flexible Pavement Design
AASHTO 1993

Performance criteria: Serviceability

- **Serviceability:** defines the ability of a pavement to serve the design traffic level

  - ***Terminal serviceability index (p_t):*** serviceability index that can be tolerated by user of roadway. 2.5 is recommended for major highways and 2.0 is for low-volume roads
  - Serviceability loss is calculated through the following equation:

$$\Delta PSI = p_o - p_t$$

p_t : terminal serviceability index

p_o : initial serviceability index

Flexible Pavement Design
AASHTO 1993

Material Properties: include characterization test results depending on the type of pavement to be designed:

- **Effective Roadbed Soil Resilient Modulus:** resilient modulus of roadbed soil (subgrade) in stress and moisture levels representing its in-situ condition (AASHTO T307)

- **Pavement Layer Materials Characterization:** elastic (resilient modulus) of pavement layers other than subgrade, i.e., subbase, base and asphalt concrete (AASHTO T307)

Flexible Pavement Design
AASHTO 1993

- **Layer coefficients:** layer coefficients are used for flexible pavements to convert layer thickness to structural number (SN) which represents the structural performance of pavement layer. Relationship between layer coefficient and structural number can be given using the following relation:

$$SN = \sum_{i=1} a_i D_i$$

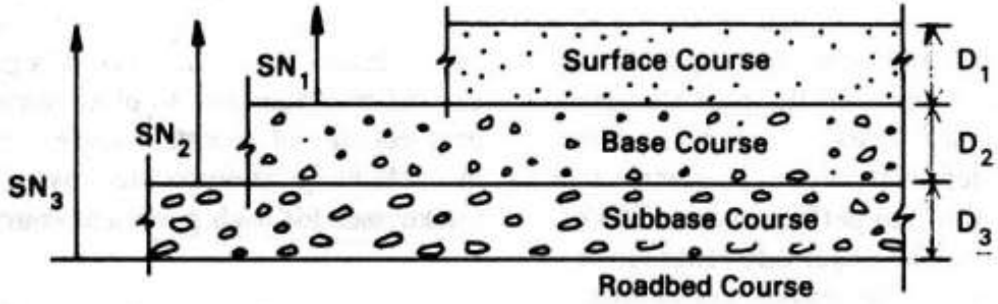
SN = structural number

a_i : layer coefficient

D_i : layer thickness

Layer coefficients are given for various materials as a function measurable material characteristics

- A



$$D^*_1 \geq \frac{SN_1}{a_1}$$

$$SN^*_1 = a_1 D^*_1 \geq SN_1$$

$$D^*_2 \geq \frac{SN_2 - SN^*_1}{a_2 m_2}$$

$$SN^*_1 + SN^*_2 \geq SN_2$$

$$D^*_3 \geq \frac{SN_3 - (SN^*_1 + SN^*_2)}{a_3 m_3}$$

1) a, D, m and SN are as defined in the text and are minimum required values.

2) 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.

Figure 3.2. Procedure for Determining Thicknesses of Layers Using a Layered Analysis Approach

NOMOGRAPH SOLVES:

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

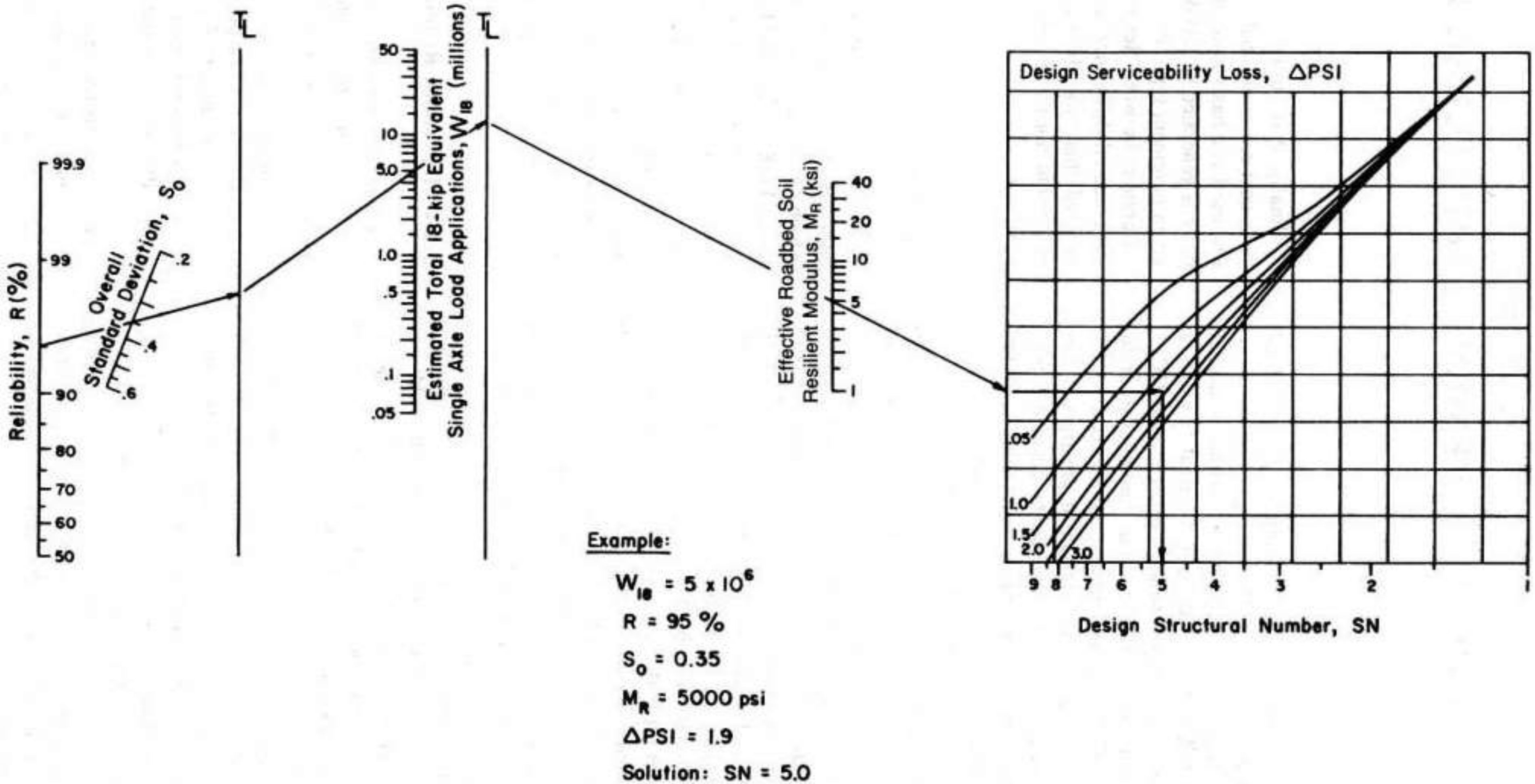


Figure 3.1. Design Chart for Flexible Pavements Based on Using Mean Values for Each Input