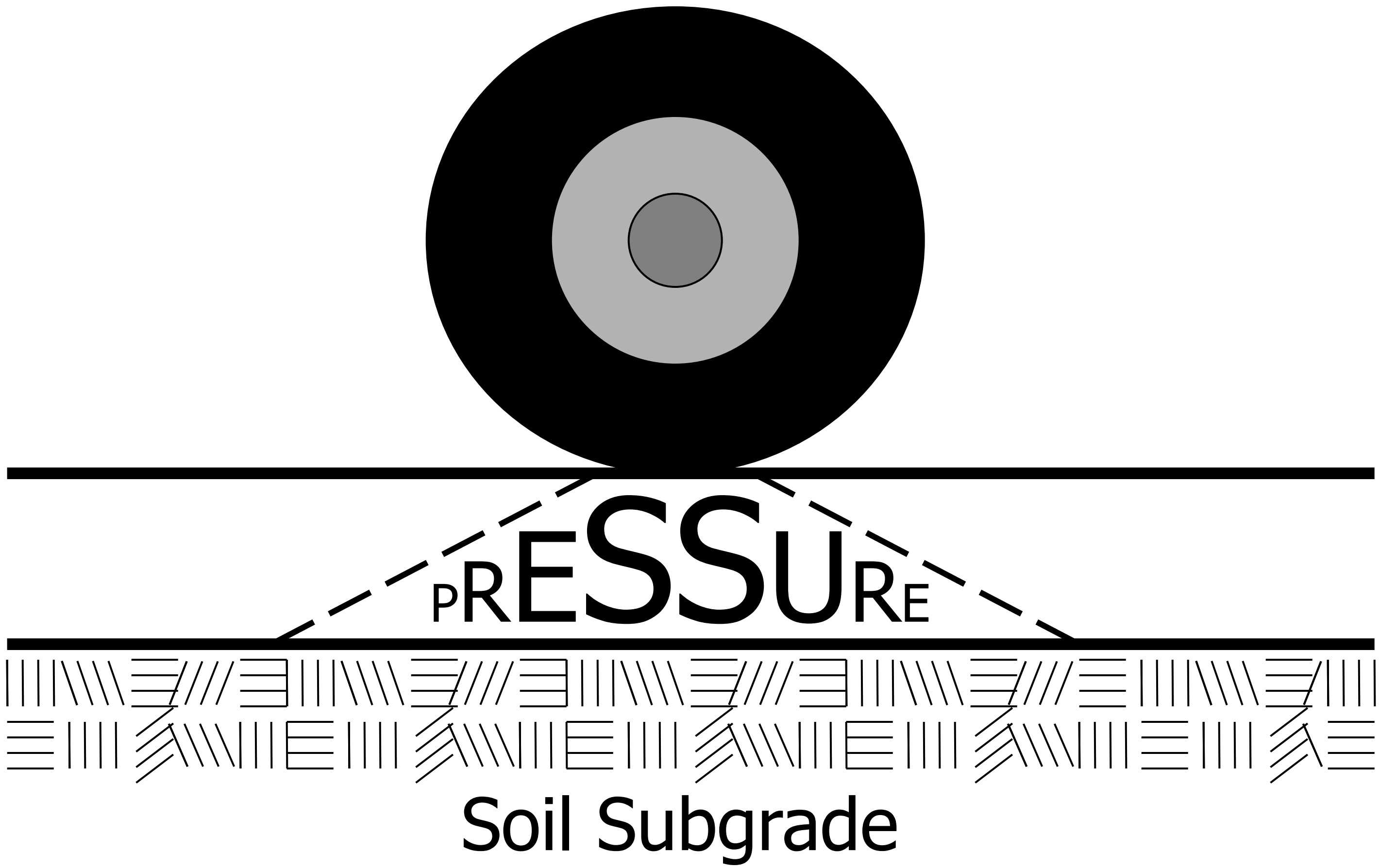
Overview of Asphalt Concrete Pavement Design

Overview of Asphalt Concrete Pavement Design

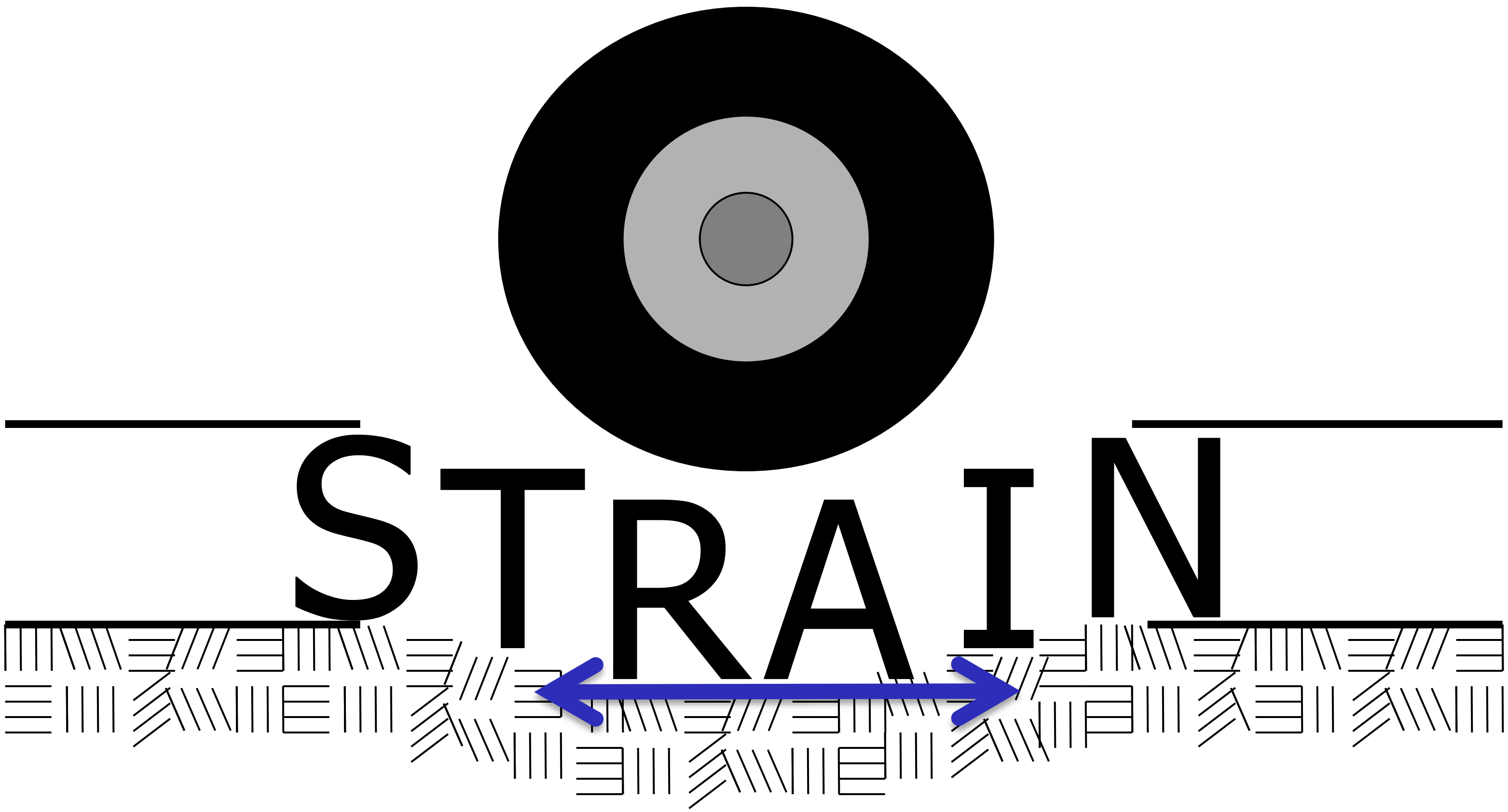
"...it is the native soil which really supports the load."
John Loudon McAdam

Overview of Asphalt Concrete Pavement Design



Design the pavement thick enough to ensure the strength of the subgrade is not exceeded for the loads to which it will be exposed.

Overview of Asphalt Concrete Pavement Design

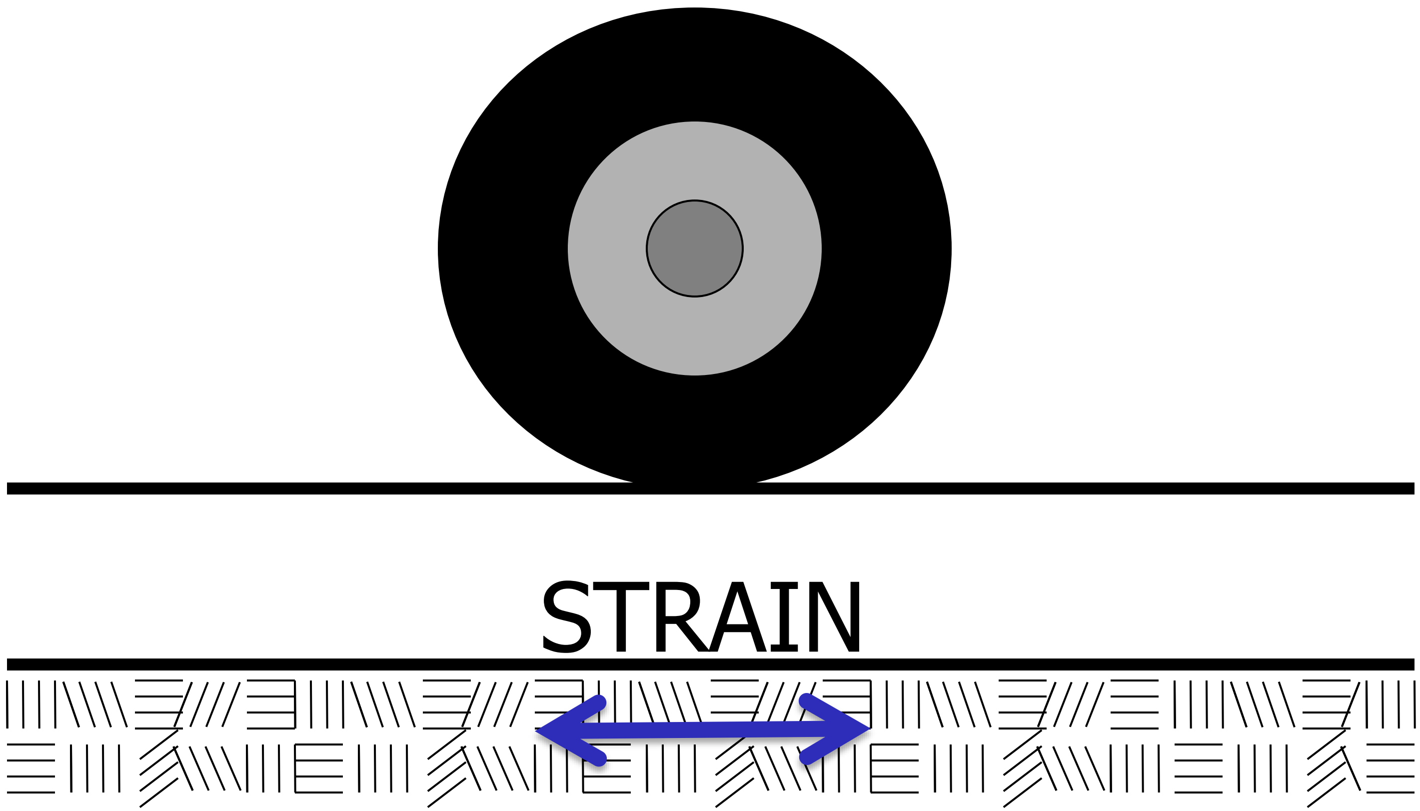


When a pavement is too thin the strength of the subgrade is exceeded and the pavement experiences high strain causing it to fatigue and eventually fail.

Overview of Asphalt Concrete Pavement Design

strain = elongation

Overview of Asphalt Concrete Pavement Design



Design the pavement thickness to ensure bending results in STRAIN < 100 $\mu\varepsilon$ (NCHRP 9-38)

Overview of Asphalt Concrete Pavement Design

Pavement Thickness Design Methods

- AASHTO
  (Empirical & Mechanistic Empirical – MEPDG)
- ODOT (AASHTO Empirical)
- Asphalt Institute (Mechanistic)
- FPO (AASHTO Empirical)

Overview of Asphalt Concrete Pavement Design

Design Factors – all design methods

- Traffic Loading (heavy trucks)
- Soil Subgrade Strength
- Pavement Materials Characteristics (strengths of materials comprising the pavement build-up)
- Environmental Conditions (Its effect on soil and pavement material strength)

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- Traffic,
- Roadbed soil,
- Materials of construction
- Environment,
- Drainage,
- Reliability,
- Life cycle costs, and
- Shoulder design

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- **<u>Pavement performance</u>** – *the pavement's structural and functional performance.*
  - *STRUCTURAL PERFORMANCE - The expectation of the pavement thickness to provide sufficient structural strength to sustain the traffic loads over the performance period;*
  - *FUNCTIONAL PERFORMANCE - The expectation of the level of "service" a pavement type will provide to the road user over its life. The dominant component of serviceability is riding comfort or ride quality. Safety is also a consideration.*

Overview of Asphalt Concrete Pavement Design

- **<u>Pavement performance</u>** (continued) – AASHTO Guide…"The serviceability-performance concept is based on five fundamental assumptions, summarized as follows:
  1. <u>Highways are for the comfort and convenience of the travelling public (User)</u>
  2. Comfort or riding quality, is a matter of subjective response or the opinion of the User.
  3. Serviceability can be expressed by the mean of the ratings given by all highway Users and is termed the serviceability rating.
  4. There are physical characteristics of a pavement which can be measured objectively and which can be related to subjective evaluations. This procedure produces an objective serviceability index.
  5. Performance can be represented by the serviceability history of a pavement."

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- **<u>Traffic</u>** – *consists of the amount, type and weight of vehicles that are expected to use the roadway. Only truck use of a roadway facility is considered since it is these types of vehicles that are sufficiently heavy to damage the pavement.*

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- Traffic,
- **Roadbed soil** – *roadbed soil is the foundation on which the pavement will be constructed. Soil strength must be known such that the pavement thickness is sufficient to spread the load induced by heavy vehicles on the soil without the soil deforming (rutting).*

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- Traffic,
- Roadbed soil,
- **Materials of construction** – *the types of materials that will be used in the pavement buildup (asphalt, concrete, crushed stone, rubblized base, etc.) their respective thickness and strengths.*

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- Traffic,
- Roadbed soil,
- Materials of construction,
- **Environment** – *addresses the impact of environment on foundation/subgrade strength. Seasonal impacts of wet, dry, freeze, non-freeze environments will affect strength of soil and non-stabilized materials (e.g. crushed stone base).*

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- Traffic,
- Roadbed soil,
- Materials of construction
- Environment,
- **<u>Drainage</u>** – *drainage (or lack thereof) impacts foundation/subgrade strength, and as such, impacts the pavement thickness. Saturated soil is weaker than dry soil. Weak soils require greater thickness. ODOT always assumes that drainage will be provided in all pavement build-ups.*

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- Traffic,
- Roadbed soil,
- Materials of construction
- Environment,
- Drainage,
- **Reliability** – *Provides consideration of uncertainties in both traffic predictions and performance predictions. Reliability is used as a safety factor. A higher level of reliability is used in the design computations when greater assurance is needed that the pavement will not fail during its life.*

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- Traffic,
- Roadbed soil,
- Materials of construction
- Environment,
- Drainage,
- Reliability,
- **Life cycle costs** – *the cost of a pavement to construct initially and maintain over the "analysis period"- in Ohio, the analysis period is typically 35 years.*

Overview of Asphalt Concrete Pavement Design

Design Considerations

The method of design provided in the AASHTO Guide includes consideration of the following items:

- Pavement performance,
- Traffic,
- Roadbed soil,
- Materials of construction
- Environment,
- Drainage,
- Reliability,
- Life cycle costs, and
- **Shoulder design** – *Related to rigid pavement design, AASHTO considers the impact of tied shoulders on pavement life.*

Overview of Asphalt Concrete Pavement Design

AASHTO Equation for the design of flexible pavements.

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

Overview of Asphalt Concrete Pavement Design

AASHTO Eqn. Thickness Design Inputs

- ALWAYS USE THE AVERAGE CONDITION/VALUE!
- USE "RELIABILITY" FACTOR AS THE MEANS BY WHICH A SAFETY FACTOR IS INCLUDED.
- <u>USING CONSERVATIVE INPUTS AND A HIGH RELIABILITY RESULTS IN EXCESSIVELY THICK PAVEMENTS</u>.

Overview of Asphalt Concrete Pavement Design

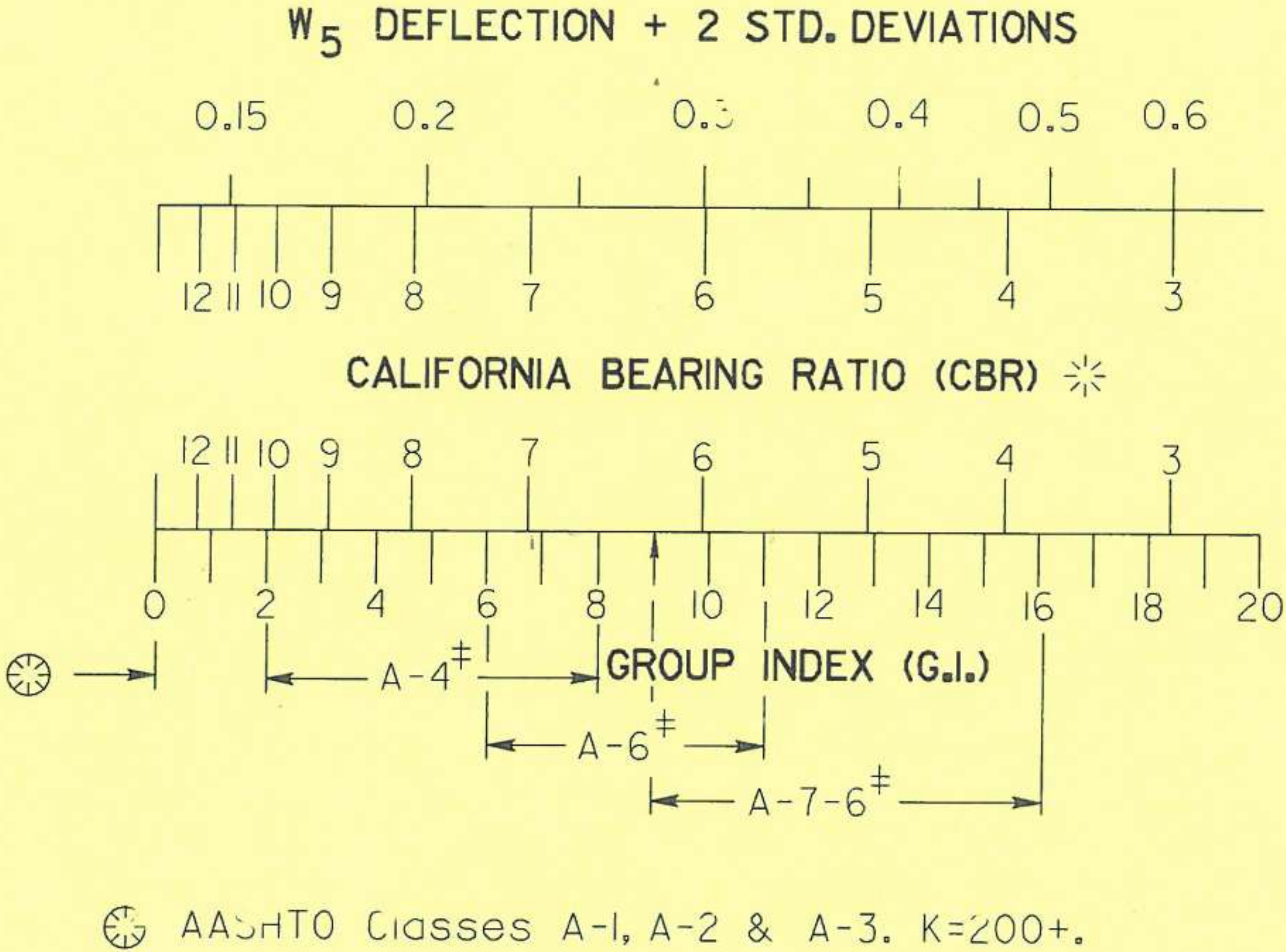
AASHTO Eqn. Thickness Design Inputs

- **<u>Performance Period</u>** (years) –
  - *The period of time used in determining pavement thickness and as the basis for forecasting future traffic loads;*
  - *In Ohio, typically assumed to be 20 years in length.*

Overview of Asphalt Concrete Pavement Design

AASHTO Eqn. Thickness Design Inputs

- Performance Period (years)
- **Soil Strength** –
  - AASHTO uses resilient modulus (M_r) as the measure of soil strength, accounting for seasonal variation in soil strength;
  - ODOT utilizes Group Index and correlates to California Bearing Ration (CBR). A multiplier is used to estimate “effective” resilient modulus, EM_r
  - (EM_r = CBR **X** 1200)

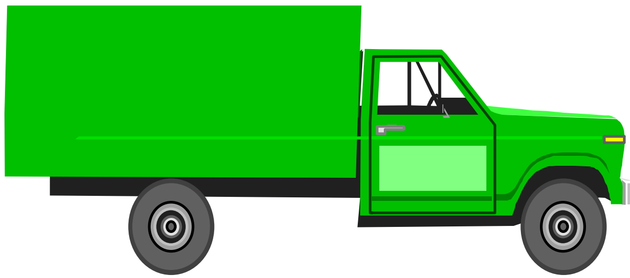

W5 DEFLECTION + 2 STD. DEVIATIONS
0.15
0.2
0.3
0.4
0.5
0.6
12 11 10 9 8 7 6 5 4 3
CALIFORNIA BEARING RATIO (CBR) *
12 11 10 9 8 7 6 5 4 3
0 2 4 6 8 10 12 14 16 18 20
GROUP INDEX (G.I.)
A-4‡
A-6‡
A-7-6‡
AASHTO Classes A-1, A-2 & A-3. K=200+.

Overview of Asphalt Concrete Pavement Design

AASHTO Eqn. Thickness Design Inputs

- Performance Period (years)
- Soil Strength
- **Traffic Loading** Over the Performance Period
  - Measured in **E**quivalent 18,000 lb. **S**ingle **A**xle **L**oads (ESAL or W_{18});
  - ESAL is a means by which the pavement damage caused by different axle configurations and truck weights can be normalized;
  - For determining the pavement thickness use the accumulated ESALs over the Performance Period.

Overview of Asphalt Concrete Pavement Design



Damage (ESAL) is a non-linear relationship to weight on the axle.

67 kN
15,000 lb
0.48 ESAL

+

27 kN
6,000 lb
0.01 ESAL

= **0.49 ESALs**

151 kN
34,000 lb
1.10

+

151 kN
34,000 lb
1.10

+

54 kN
12,000 lb
0.19

= **2.39 ESALs**

Axle load equivalency factor (axle configuration dependent)

Overview of Asphalt Concrete Pavement Design

- **<u>Traffic Loading</u>** (continued)
  - Consider directional distribution of heavy trucks (i.e. is the truck traffic consistent both directions? If no, design for direction with heaviest traffic.)
  - Lane Factor – for multilane pavements design the thickness based on the lane that carries the greatest number of trucks.

Overview of Asphalt Concrete Pavement Design

- **<u>Traffic Loading</u>**
  ODOT Pavement Design Guide Sec. 200

  $$\text{B-ESALs} = ADT * \%T_{24} * \%D * \%LF * \%B * CF$$
  $$\text{C-ESALs} = ADT * \%T_{24} * \%D * \%LF * \%C * CF$$

  B-ESALs + C-ESALs = Total Daily ESALs

  ADT = Average Daily Traffic
  $\%T_{24}$ = 24-hour truck percentage of ADT
  %D = Directional Distribution
  %LF = Lane Factor (percent trucks in the design lane)
  %B,C = % B (tractor trailer) or %C (straight body) trucks of the total trucks
  CF = Truck conversion factor (ESALs per truck) based on Functional Classification of the Roadway

Overview of Asphalt Concrete Pavement Design

- **<u>Traffic Loading</u>**
  ODOT Pavement Design Guide Sec. 200

  $$B\text{-}ESALs = ADT * \%T_{24} * \%D * \%LF * \%B * CF$$
  $$C\text{-}ESALs = ADT * \%T_{24} * \%D * \%LF * \%C * CF$$

  B-ESALs + C-ESALs = Total Daily ESALs

  ADT = Average Daily Traffic
  $\%T_{24}$ = 24-hour truck percentage of ADT
  %D = Directional Distribution
  %LF = Lane Factor (percent trucks in the design lane)
  %B,C = % B (tractor trailer) or %C (straight body) trucks of the total trucks
  CF = Truck conversion factor (ESALs per truck) based on Functional Classification of the Roadway

Overview of Asphalt Concrete Pavement Design

- **Traffic Loading**

  ODOT Pavement Design Guide Sec. 200

CAUTION !

ODOT uses average weight of trucks for determining ESALs.

When designing a specific parking facility use actual truck weights.

B-ESALs = ADT * $\%T_{24}$ * %D * %LF * %B * CF

C-ESALs = ADT * $\%T_{24}$ * %D * %LF * %C * CF

B-ESALs + C-ESALs = Total Daily ESALs

ADT = Average Daily Traffic

$\%T_{24}$ = 24-hour truck percentage in ADT

%D = Directional Distribution

%LF = Lane Factor (percent trucks in the design lane)

%B,C = % B (tractor trailer) or %C (straight body) trucks of the total trucks

CF = Truck conversion factor (ESALs per truck) based on Functional Classification of the Roadway

Overview of Asphalt Concrete Pavement Design

AASHTO Eqn. Thickness Design Inputs

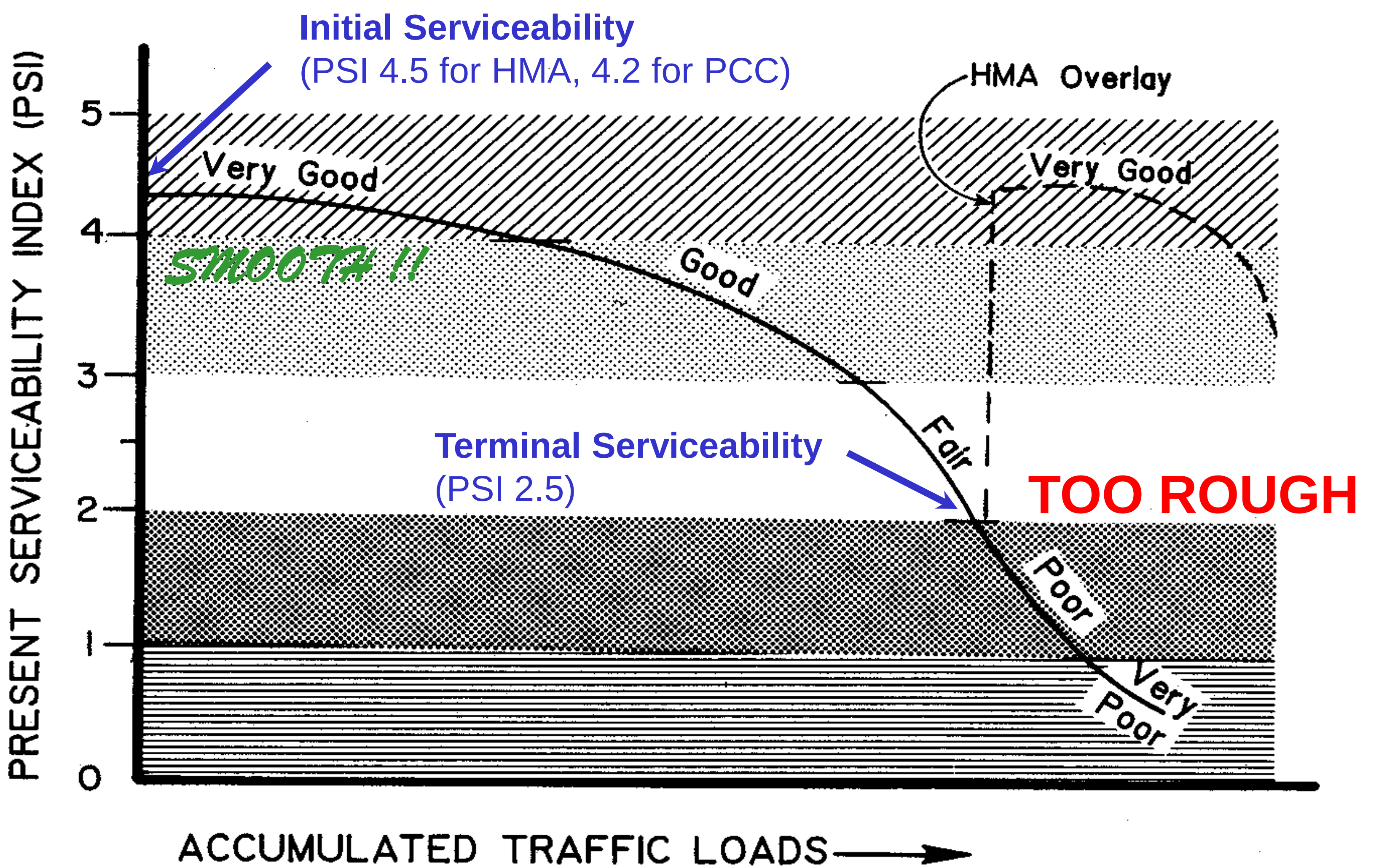
- Performance Period (years)
- Soil Strength
- Traffic Loading (accumulated ESALs) Over Performance Period
- **Climate Conditions** – the effect of seasonal changes on the pavement foundation performance and strength. For instance, addressing frost-susceptible soils and accounting for soil support during thaw.

Overview of Asphalt Concrete Pavement Design

AASHTO Eqn. Thickness Design Inputs

- Design Period (years)
- Soil Strength
- Traffic Loading (accumulated ESALs) Over Performance Period
- Climate Conditions
- **Loss of Serviceability** **(ΔPSI)** – the amount of serviceability (riding comfort) the agency will tolerate losing before rehabilitation is needed.

Overview of Asphalt Concrete Pavement Design



$$\Delta PSI = P_o - P_t$$

Overview of Asphalt Concrete Pavement Design

Reference: AASHTO Guide

Terminal Serviceability Level (P_t)	**Percent of People Stating Unacceptable**
3.0	12
2.5	55
2.0	85

Overview of Asphalt Concrete Pavement Design

Reference: ODOT Pavement Design Guide

SERVICEABILITY FACTORS		
	RIGID/COMPOSITE	FLEXIBLE
Initial Serviceability	4.2	4.5
Terminal Serviceability	2.5	2.5
Design Serviceability Loss	1.7	2.0

Overview of Asphalt Concrete Pavement Design

AASHTO Eqn. Thickness Design Inputs

- Design Period (years)
- Soil Strength
- Traffic Loading (accumulated ESALs) Over Performance Period
- Climate Conditions
- Loss of Serviceability (ΔPSI)
- **Reliability "R"** (safety factor) – Absent a reliability factor the probability that the pavement will provide useful service over its intended life is **50 percent**. Increasing the reliability has the effect of increasing the traffic which in turn increases pavement thickness and the probability of meeting the intended life.

Overview of Asphalt Concrete Pavement Design

Reference: AASHTO Guide Table 2.2, Suggested levels of reliability for various functional classifications

Functional Classification	**Recommended Level of Reliability (%)**	
	Urban	Rural
Interstate and other freeways	85 – 99.9	80 – 99.9
Principal Arterials	80 – 99	75 – 95
Collectors	80 – 95	75 – 95
Local	50 – 80	50 – 80

Overview of Asphalt Concrete Pavement Design

Reference: ODOT Pavement Design Guide, Plate 201-1

Functional Classification	**Recommended Level of Reliability (%)**	
	Urban	Rural
Interstate and freeway	95	90
Principal and Minor Arterials	90	85
Collectors	90	85
Local	80	80

Overview of Asphalt Concrete Pavement Design

AASHTO Eqn. Thickness Design Inputs

- Design Period (years)
- Soil Strength
- Traffic Loading (accumulated ESALs) Over Performance Period
- Climate Conditions
- Loss of Serviceability (ΔPSI)
- Reliability "R" (safety factor)
- **Overall Standard Deviation** (variability) – accounts for the chance variation in the traffic prediction and chance variation in actual performance.

Overview of Asphalt Concrete Pavement Design

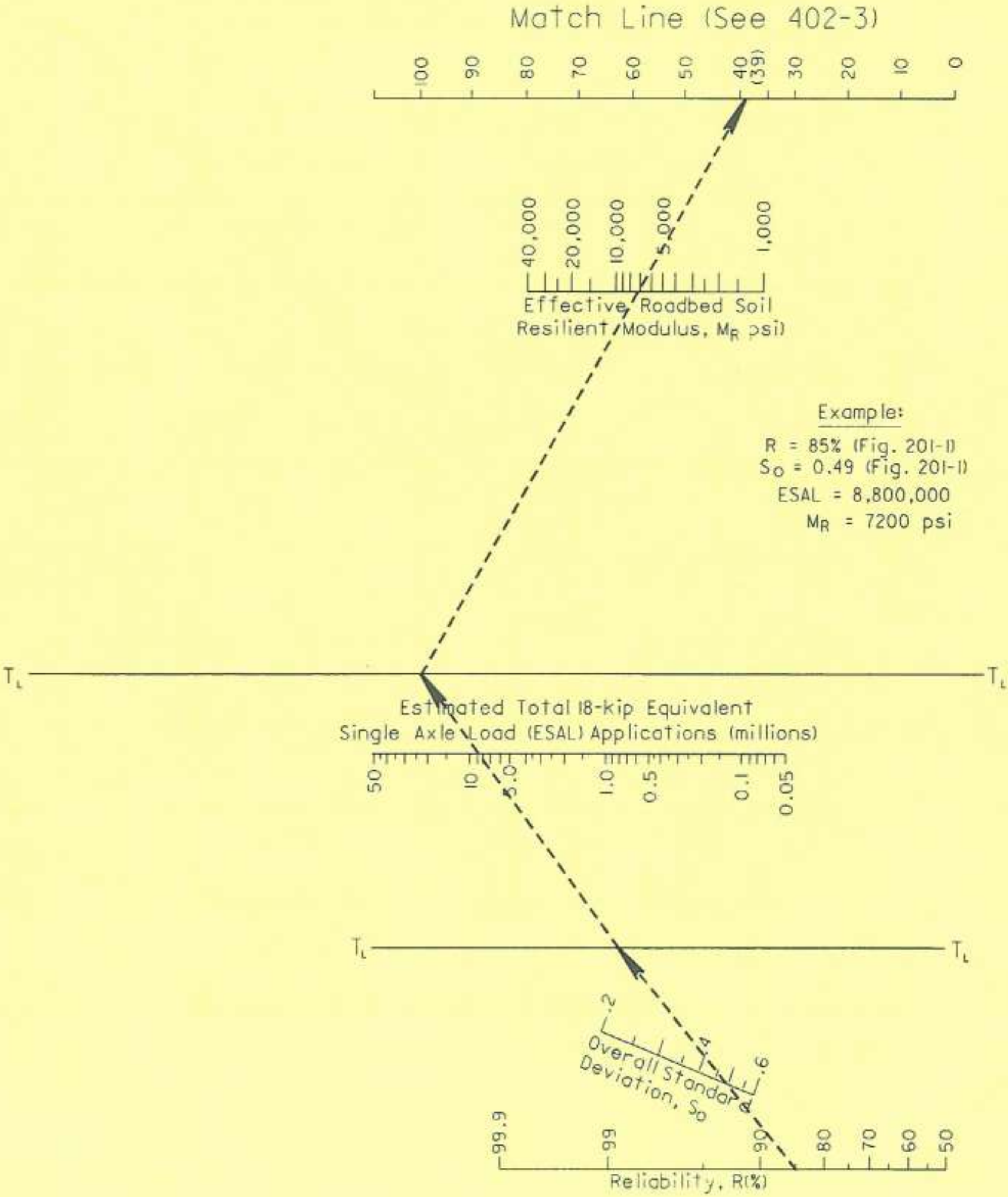
Reference: ODOT Pavement Design Guide, Plate 201-1

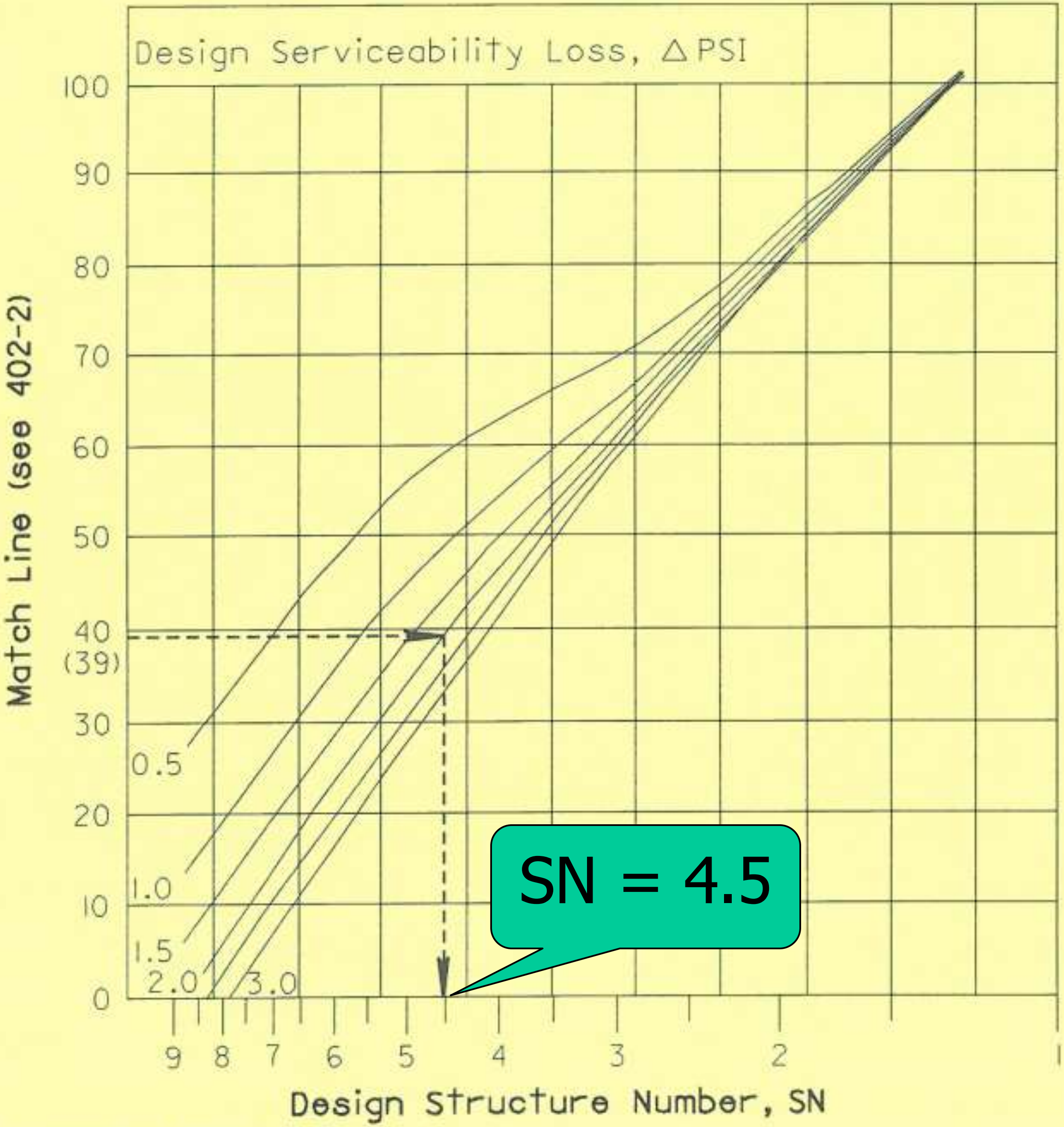
OVERALL STANDARD DEVIATION (δ_o)	
Flexible Pavement	0.49
Rigid Pavement	0.39

Overview of Asphalt Concrete Pavement Design

DETERMINE Structural Number (SN) using AASHTO Equation/nomograph

SN is an abstract number (SN) that represents the structural strength required for a pavement to perform in accordance with the design criteria.


Match Line (See 402-3)
100 90 80 70 60 50 40 (39) 30 20 10 0
40,000 20,000 10,000 5,000 1,000
Effective Roadbed Soil
Resilient Modulus, M_R psi)
Example:
R = 85% (Fig. 201-1)
S_o = 0.49 (Fig. 201-1)
ESAL = 8,800,000
M_R = 7200 psi
T_L
Estimated Total 18-kip Equivalent
Single Axle Load (ESAL) Applications (millions)
50 10 5.0 1.0 0.5 0.1 0.05
.2 .4 .6
Overall Standard
Deviation, S_o
99.9 99 90 80 70 60 50
Reliability, R(%)



Example: ΔPSI = 2.0

Solution: SN = 4.5

Overview of Asphalt Concrete Pavement Design

DETERMINE THE PAVEMENT BUILDUP

Flexible pavements are comprised of a layered system of various materials wherein each layer contributes to the overall structural number of the pavement.

4.5

$$SN = a_1*D_1 + a_2*D_2*m_2 + a_3*D_3*m_3 + \ldots$$

a = layer coefficient represents the structural strengths (per inch) of a material in the buildup.

D = the thickness of the material

m = drainage coefficient (assumed to be 1.0 since drainage is "always" provided.

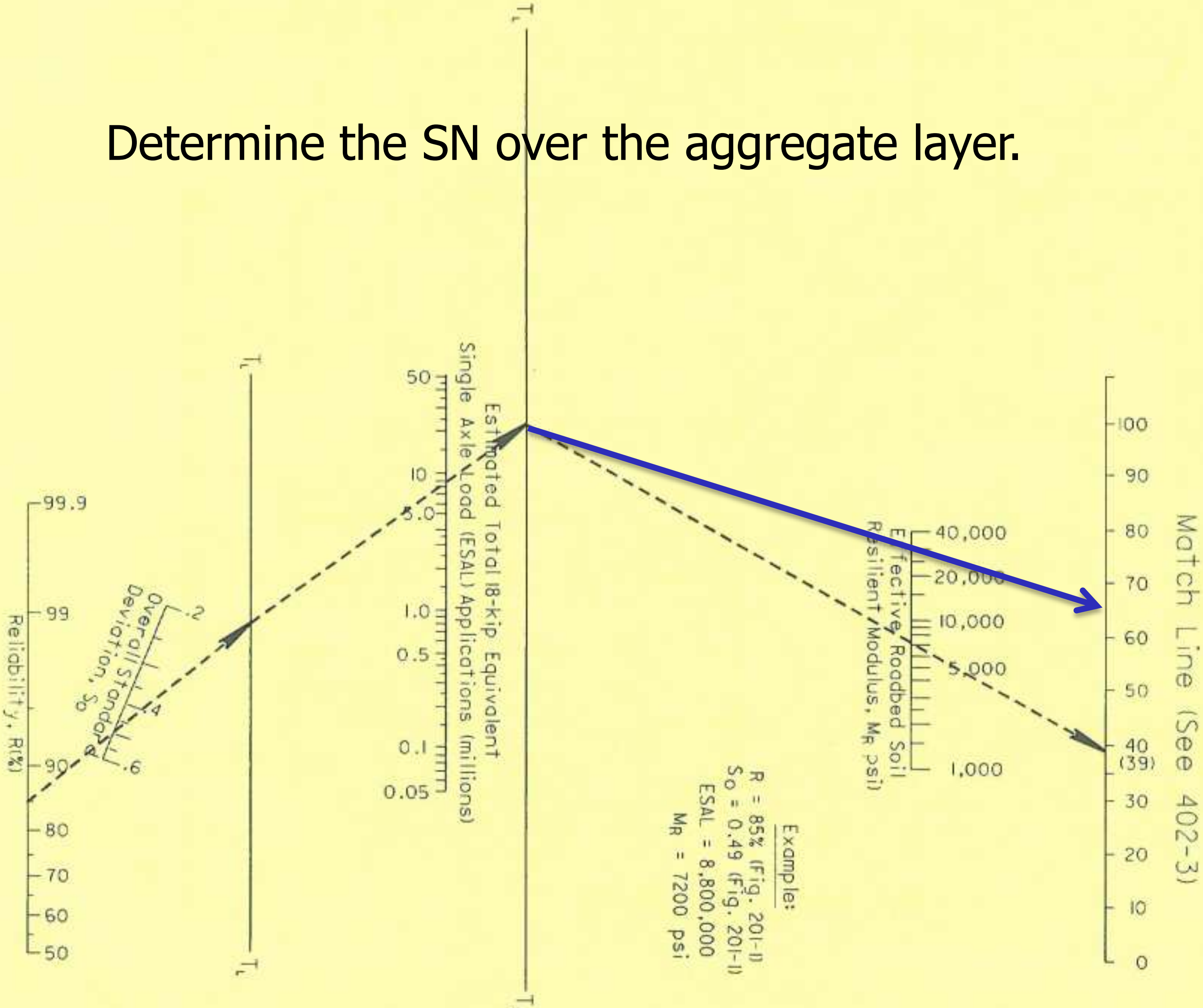
Overview of Asphalt Concrete Pavement Design

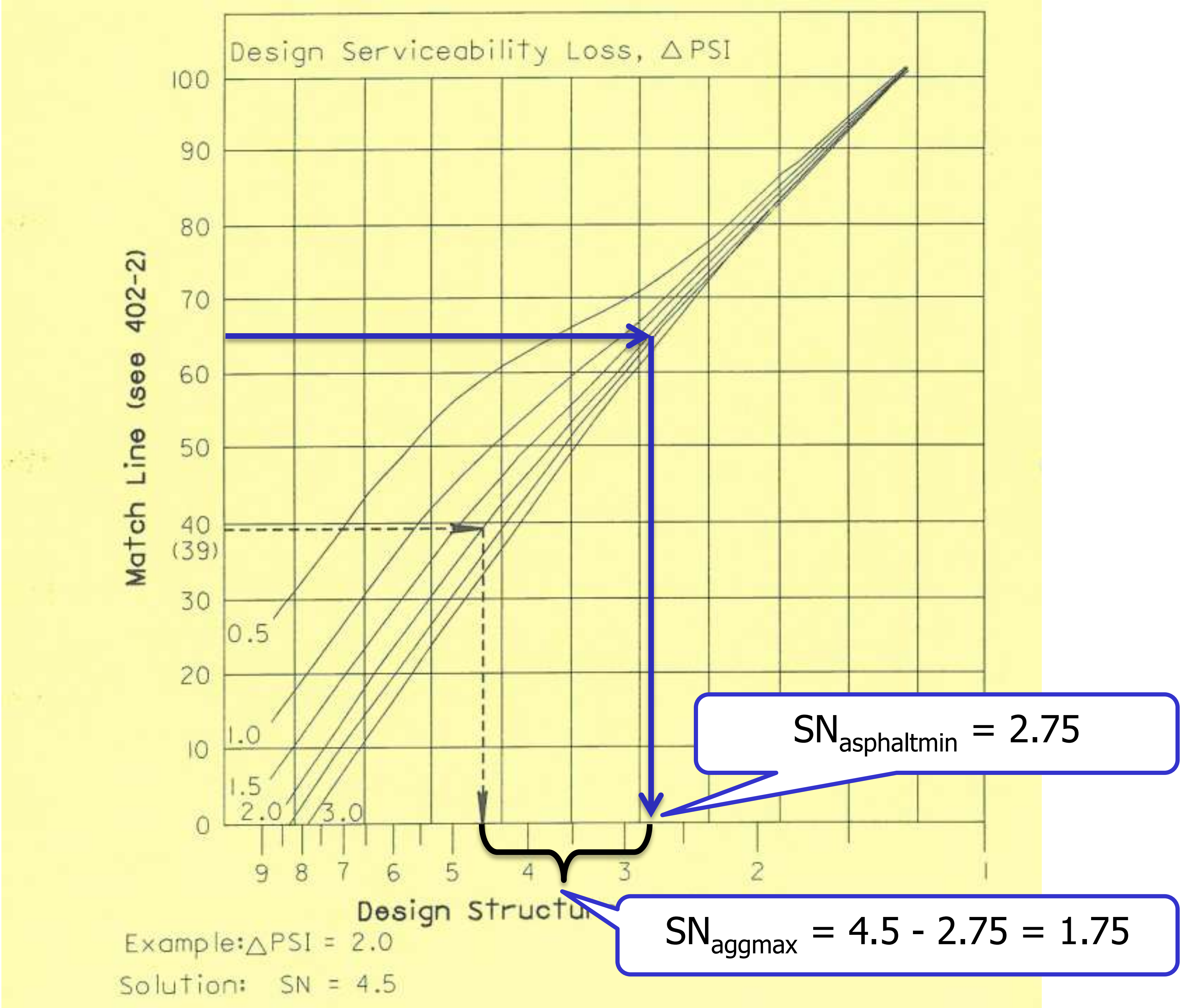
"LAYERED DESIGN ANALYSIS"

DETERMINE THE MAXIMUM ALLOWABLE THICKNESS OF EACH UNBOUND LAYER (i.e. aggregate layer), AND DETERMINE THE MINIMUM THICKNESS OF THE ASPHALT LAYER.

REASON: WE WANT TO AVOID OVER-BENDING THE ASPHALT LAYER – CAUSING IT TO FATIGUE -AND AVOID PUTTING THE AGGREGATE LAYER INTO TENSION (WHY? The strength of the aggregate base layer comes only when it is in compression.)

Determine the SN over the aggregate layer.





Design Serviceability Loss, △PSI
Match Line (see 402-2)
100
90
80
70
60
50
40
(39)
30
20
10
0
0.5
1.0
1.5
2.0
3.0
9
8
7
6
5
4
3
2
1
Design Structu
Example:△PSI = 2.0
Solution: SN = 4.5
$SN_{asphaltmin}$ = 2.75
SN_{aggmax} = 4.5 - 2.75 = 1.75

Overview of Asphalt Concrete Pavement Design

<u>"LAYERED DESIGN ANALYSIS"</u>

$SN = a_1*D_1 + a_2*D_2*m_2 + a_3*D_3*m_3 + \ldots$

$4.5 = SN_{asphaltmin} + SN_{aggmax}$

$4.5 = 2.75 + 1.75$ (ensures min. and max. lift thickness requirements are met)

a = layer coefficient represents the structural strengths (per inch) of a material in the buildup.

D = the thickness of the material

m = drainage coefficient (assumed to be 1.0 since drainage is "always" provided.

Overview of Asphalt Concrete Pavement Design

<u>"LAYERED DESIGN ANALYSIS"</u>

4.5 = 2.75 + 1.75 (ensures min. and max. lift thickness requirements are met)

When selecting appropriate values for the layer thicknesses, it is necessary to consider their…

- Cost effectiveness
- Construction constraints
- Maintenance constraints

Overview of Asphalt Concrete Pavement Design

Reference: ODOT Pavement Design Guide, Plate 401-1

ASPHALT CONCRETE STRUCTURAL COEFFICIENTS (a_i)	
Items 424, 442, 443, 446, 448, 826, 857, 859, 874 – AC Surface	0.43
Items 442, 443, 446, 448, 826, 857 – AC Intermed.	0.43
Items 301, 302 AC Base Course.	0.36
Item 304 – Aggregate Base	0.14
Item 320 – Rubblized Concrete	0.14

Overview of Asphalt Concrete Pavement Design

<u>**“LAYERED DESIGN ANALYSIS”**</u>

$4.5 = 2.75 + 1.75$ (ensures min. and max. lift thickness requirements are met)

<u>**Max aggregate thickness**</u>:

$SN_{aggmax} = 1.75 = 0.14*D_{aggmax}*1$

$D_{aggmax} = 1.75 \div 0.14 =$ <u>12.5 inches maximum thickness agg. base</u>

<u>**Min asphalt thickness**</u>:

$SN_{asphaltmin} = 2.75 = SN_{surface} + SN_{intermediate} + SN_{base}$

$SN_{base} = 2.75 – 0.43*1.5 – 0.43*1.75 = 1.35$

[note: surface and intermediate course thickness is assumed]

$D_{base} = 1.35 \div 0.36 = 3.75$ inches

$D_{asphaltmin} = 1.5 + 1.75 + 3.75 =$ <u>7 inch minimum thickness asphalt</u>

QUESTIONS?