2015 North Dakota Asphalt Conference

NDDOT Implementation of AASHTO Flexible Pavement Design

Part I – ADT & ESALs – Nickie Reis, P&AM
Part II – Structural Numbers – Tom Bold, M&R

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Process of going from traffic counts to ESALs (Equivalent Single Axle Load)

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It all begins with Traffic!

- Without a quality traffic count everything is based on assumptions or best estimates.
- A traffic count doesn't do much good if it has incorrect data.

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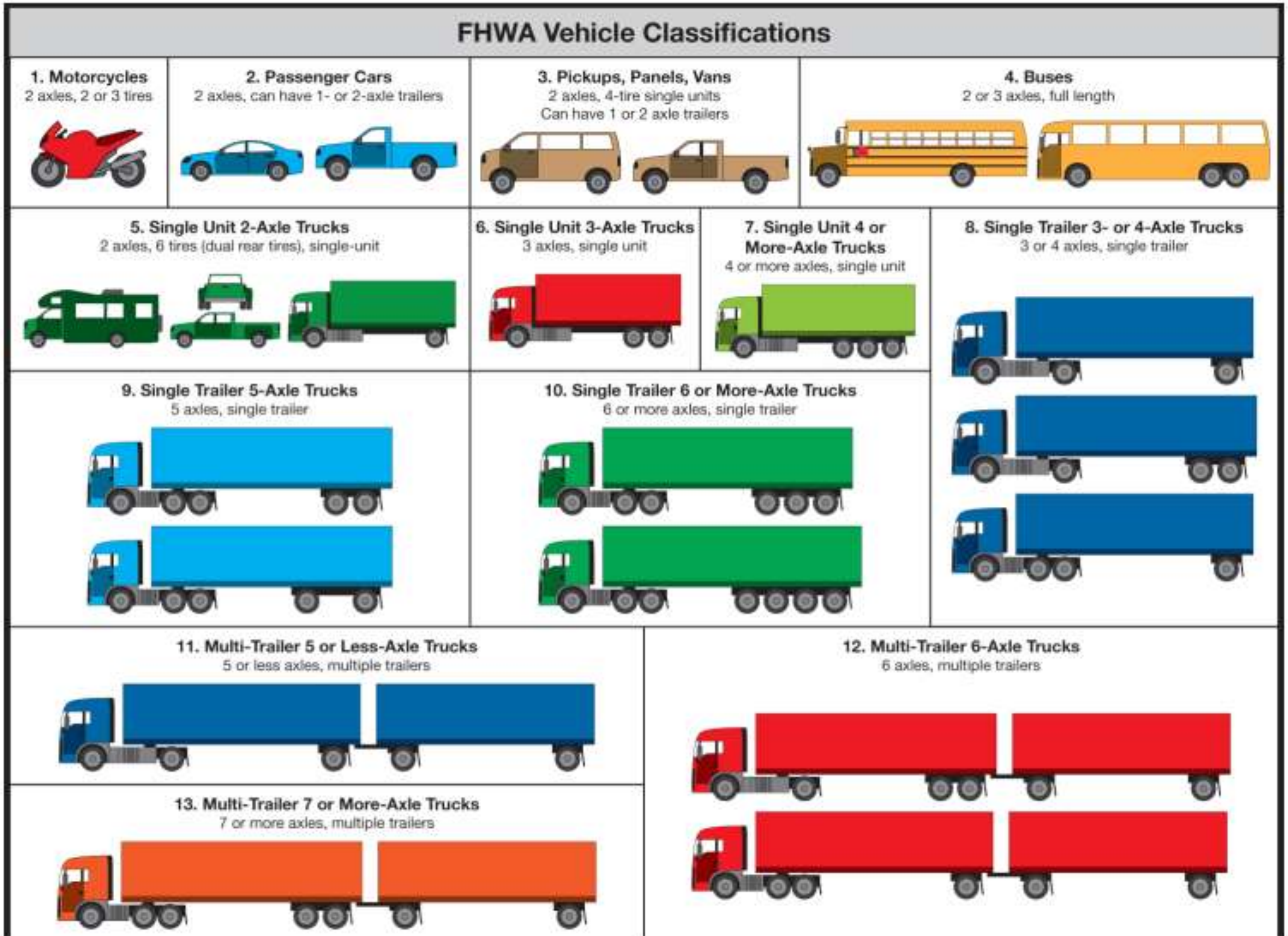
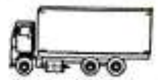
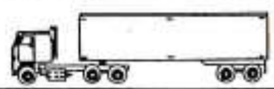
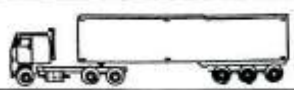
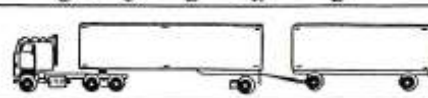
Traffic Counts

- NDDOT collects traffic using portable Automatic Data Recorders (ADRs) to obtain 24 hour data at class locations.
- NDDOT also uses permanent Automatic Traffic Recorders (ATRs) that collect traffic data every day throughout the year
- Both methods collect traffic based on Class FHWA scheme “F” 13 vehicle classification tree
- Classification scheme is how the ATR’s and the portable counters “see” the various truck axle configurations

FHWA 13 Vehicle Classification (Scheme F)



(Scheme F) without Classes 1-4

CLASSIFICATION TYPE	VEHICLE TYPE	NO. OF AXLES
5		2
6		3
7		4
8		3
		4
		4
9		5
		5
10		6
11		5
12		6
13		7 or more

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Equivalent Single Axle Load (ESAL)

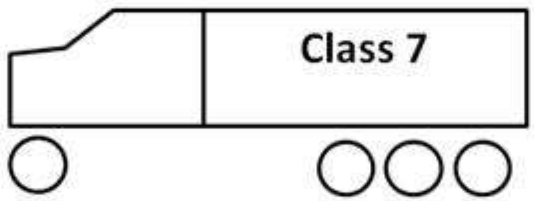
- ESAL- is the relationship between axle weight and pavement damage.
- The reference axle load is an 18,000-lb. single axle with dual tires.
- Developed by the American Association of State Highway Officials (AASHO) Road Test

Loaded ESAL Values by Truck type

Based on AASHTO Guide for Design of Pavement Structures 1993 – Appendix D

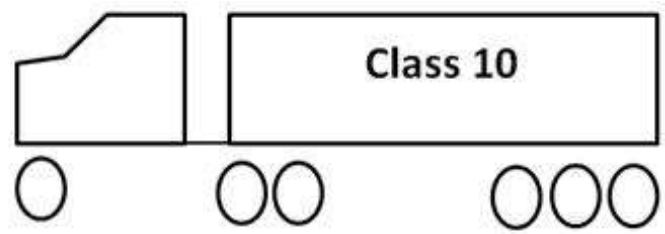
Assumed Pt= 2.5 & Sn=2

- The Sn changes based on the cross section of the existing roadway
- 4 inches of Asphalt and 10 inches of Base would represent a Sn=2



			Total
Weight (lb 000s)	16	42	58
ESALS (Flex)	.613	.594	

Total ESALs =**1.207**



				Total
Weight (lb 000s)	12	34	42	88
ESALS (Flex)	.198	1.08	.594	

Total ESALs = **1.872**

Loaded ESAL Values by Truck type

Based on AASHTO Guide for Design of Pavement Structures 1993 – Appendix D

Assumed Pt= 2.5 & Sn=2

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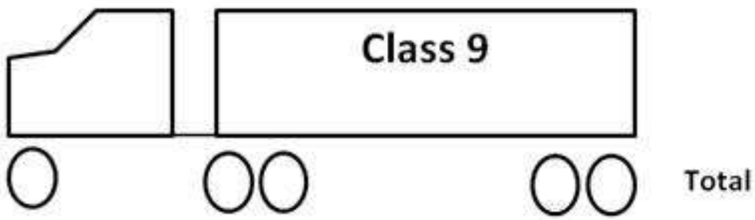
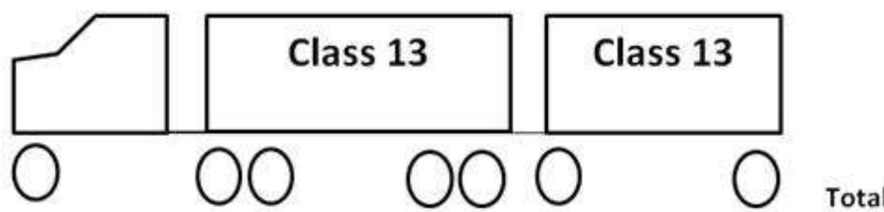
- 4 inches of Asphalt and 10 inches of Base would represent a Sn=2



Weight (lb 000s)	12	34	34	80
ESALS (Flex)	.198	1.08	1.08	

Total ESALs =**2.358**



Weight (lb 000s)	12	34	34	13	12.5	105.5
ESALS (Flex)	.198	1.08	1.08	0.278	0.238	

Total ESALs = **2.874**

Loaded ESALs by Vehicle Class Distribution

Class Type	% Type	Truck Volume	Number of Trucks	Flex ESAL Rate (loaded)	Flexible ESALS Per Type	Weight (LBS)
Class 5	5	1000	50	1.768	88.4	32,000
Class 6	2	1000	20	1.278	25.56	46,000
Class 7	1	1000	10	1.207	12.07	58,000
Class 8	12	1000	120	2.848	341.76	66,000
Class 9	66	1000	660	2.358	1556.28	80,000
Class 10	6	1000	60	1.872	112.32	88,000
Class 11	1	1000	10	6.478	64.78	92,000
Class 12	1	1000	10	5.988	59.88	105,500
Class 13	6	1000	60	2.874	172.44	105,500
				Total=	2433.49 ESALs	

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Difference in Assuming all trucks are in a certain vehicle Class

- 1000 trucks x 2.358 ESALs (**Class 9**)= 2358 ESALs
- 1000 trucks x 2.874 ESALs (**Class 13**)= 2874 ESALs
- Difference between Class 13 & Class 9

  2874 -2358 = <u>516 ESALs</u>
- 516 ESALs x 365 days in a year x 20 years equals a difference of **<u>3,766,800 ESALs</u>**.
- By not knowing what class of trucks that are on the roadway can have a significant impact on the design.

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Traffic Estimate

- After the traffic count is taken and ESALs calculated a growth rate is applied.
- There are no set standard growth rates.
- Growth rates are usually based on traffic history, economic activity in the area & local knowledge of future traffic generators.
- The information then gets sent to materials for their part.

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(or, NDDOT AASHTO Pavement Design Inputs)

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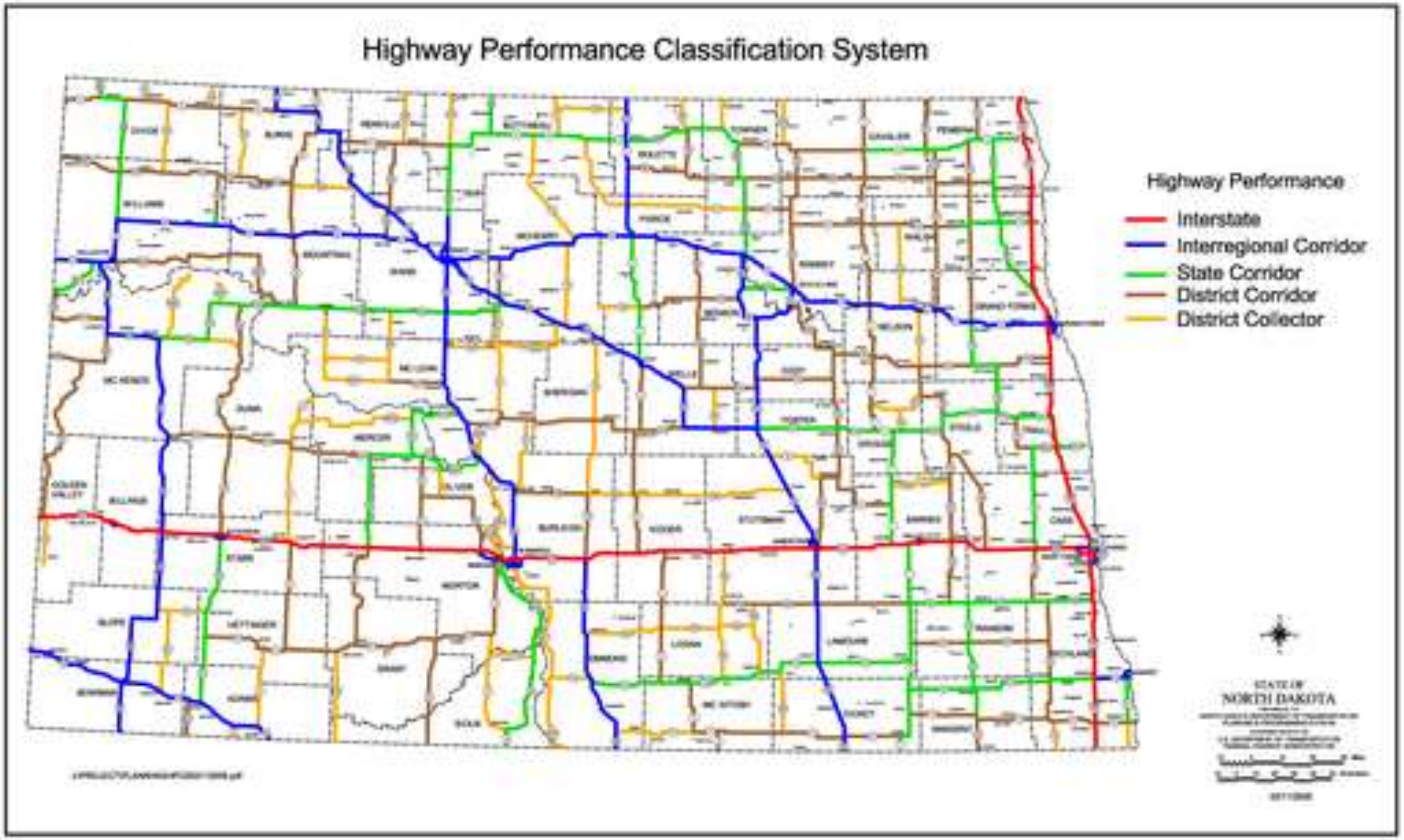
Highway Performance Class & Investment Strategies



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AASHTO Flexible Pavement Design Equation

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

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AASHTO Flexible Pavement Design Equation

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

Predicted Damage over the Design Period (Accumulated ESALs)

=

Pavement Structure Required Based on:

- Available Foundation Soil Strength
- Condition at the End of the Design Period
- Acceptable Level of Risk

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Design Input Factors

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

W_{18} = ***Accumulated ESALS***

Z_R = ***Reliability Factor***

S_o = ***Standard Deviation***

SN = ***Structural Number***

ΔPSI = ***Serviceability Index***

M_R = ***Subgrade Resilient Modulus*** *(in psi)*

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Traffic Counts & Future Growth Rate

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

W_{18} = *Total Accumulated Flexible ESALs for Pavement Design Period*

- Predicted Number of 18,000 lb. Axle Loadings (1 - 18kips = ESAL)

  - $T/2 \times 365 \times \left[\frac{(1+i)^n - 1}{i}\right]$

Where:

T = Two-Way Daily Flexible ESALs

i = Growth Rate

n = Design Period, (20 years for flexible pavements)

Z_R = Reliability

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

Z_R = ***Reliability Factor (Risk)***

NDDOT Performance Class	New Construction (Reliability %)	Rehabilitation (Reliability %)
Interstate	90%	85%
Interregional Corridor	85%	80%
State Corridor	80%	80%
District Corridor	75%	75%
District Collector	70%	70%

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S_O = Standard Deviation

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

S_o = ***Standard Deviation***

- Combined Standard Error of the Traffic Prediction and Performance Prediction
- NDDOT uses 0.49

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SN = Structural Number

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

SN = ***Structural Number***

- Indicative of the total pavement thickness required

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots$$

where: a_i = i^{th} layer coefficient

D_i = i^{th} layer thickness (inches)

m_i = i^{th} layer drainage coefficient

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SN = Structural Number

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

New or Reconstructed Pavements

SN = $\mathbf{a_1}D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots$

- a_i = i^{th} Layer Coefficient
  - New HBP Superpave Material

20 yr. Accumulated Design ESALS		
< 400,000	FAA 40	= 0.34
400,000 to < 1,000,000	FAA 42-43	= 0.36
1,000,000 to 3,000,000	FAA 44	= 0.38
>3,000,000	FAA 45	= 0.40

  - New Cold In-Place Recycling = 0.25

SN = Structural Number

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

Structural Overlays

SN = $a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots$

- a_1 = i^{th} Layer Coefficient
  - New HBP Superpave Material

20 yr. Accumulated Design ESALS		
< 400,000	FAA 40	= 0.34
400,000 to < 1,000,000	FAA 42-43	= 0.36
1,000,000 to 3,000,000	FAA 44	= 0.38
>3,000,000	FAA 45	= 0.40

- a_2 = i^{th} Layer Coefficient
  - Existing HBP Material = 0.25

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Bituminous Recommendations

Performance Graded Binders

- Selection Based on Project Type & ESALs
  - New or Reconstruction
    - Lower lifts – PG 58-28
    - Upper Lifts – PG 58-34, 64-28/34, 70-28, 76-28
  - Overlays
    - PG 58-28, 64-28, 70-28, 76-28

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20 yr. Accumulated Design ESALS

< 400,000	PG 58-XX
400,000 to < 1,000,000	PG 58-XX
1,000,000 to 3,000,000	PG 58-XX
>3,000,000	PG 58-XX & Above

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SN = Structural Number

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

SN = $a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots$

- a_i = i[th] Layer Coefficient
  - New & Existing Base Materials
    - Aggregate Base:
      - Sand Base = 0.06
      - Class 3 = 0.08
      - Class 5 = 0.10
    - Emulsified Base = 0.10 to 0.20
    - Blended Base = 0.10
    - New Cement Treated Base = 0.18
    - New Cement Treated Subgrade = 0.12

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SN = Structural Number

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

SN = $a_1 \mathbf{D_1} + a_2 \mathbf{D_2} m_2 + a_3 D_3 m_3 + \ldots$

- D_i = i^{th} Layer Depth Thickness
  - Existing Materials
    - Pavement
      - Milestone Cores Obtained by District Personnel
      - RIMS Historical Data
    - Base
      - Field Aggregate Depth Checks
      - RIMS Historical Data

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SN = Structural Number

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

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

- D_i = i^{th} Layer Depth Thickness
  - New Materials
    - Pavement
      - 1:3 Ratio (HBP : Base)
      - Design Thickness is Rounded to the Nearest ½ inch
    - Base
      - Thicker Bases Perform Better
      - Typical Base Thickness – 8",12",15",18" ,etc.

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SN = Structural Number

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

$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots$

- m_i = i^{th} Drainage Coefficient
  - Aggregated Bases Generally Provide Some Level of Drainage
  - NDDOT Uses Drainage Coefficient of 1.0

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ΔPSI = Serviceability

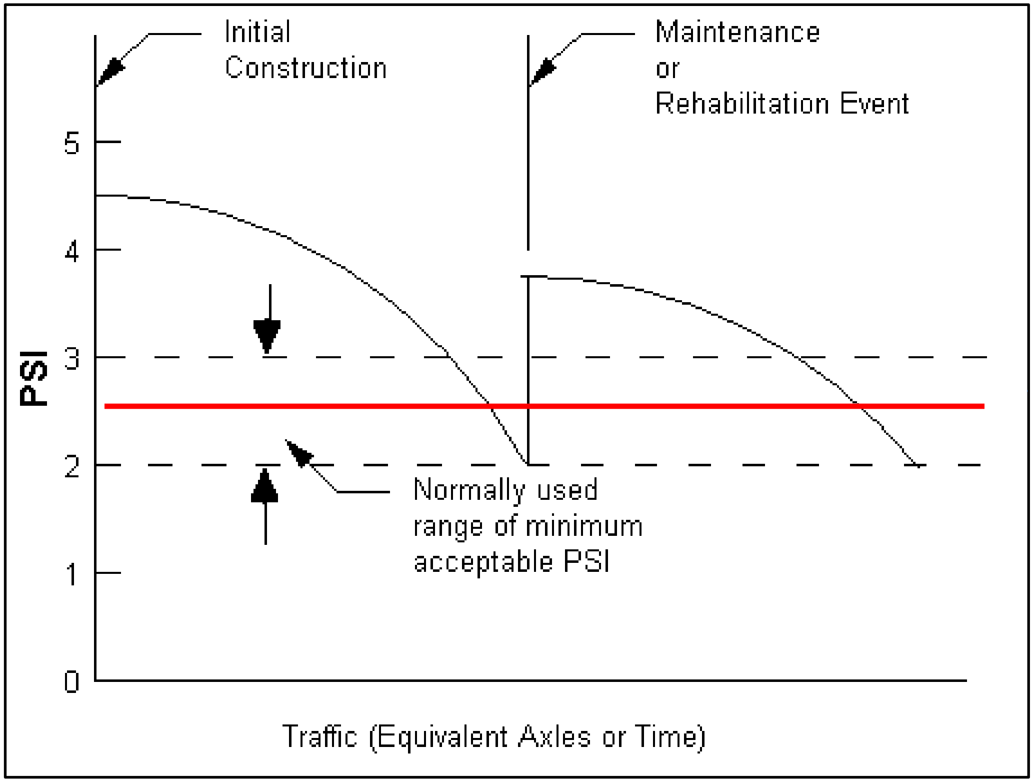
$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

p_o - p_t = ΔPSI

p_o = 4.5 (Initial Serviceability)

p_t = 2.5 (Terminal Serviceability)

ΔPSI = 2.0 (Serviceability Index)



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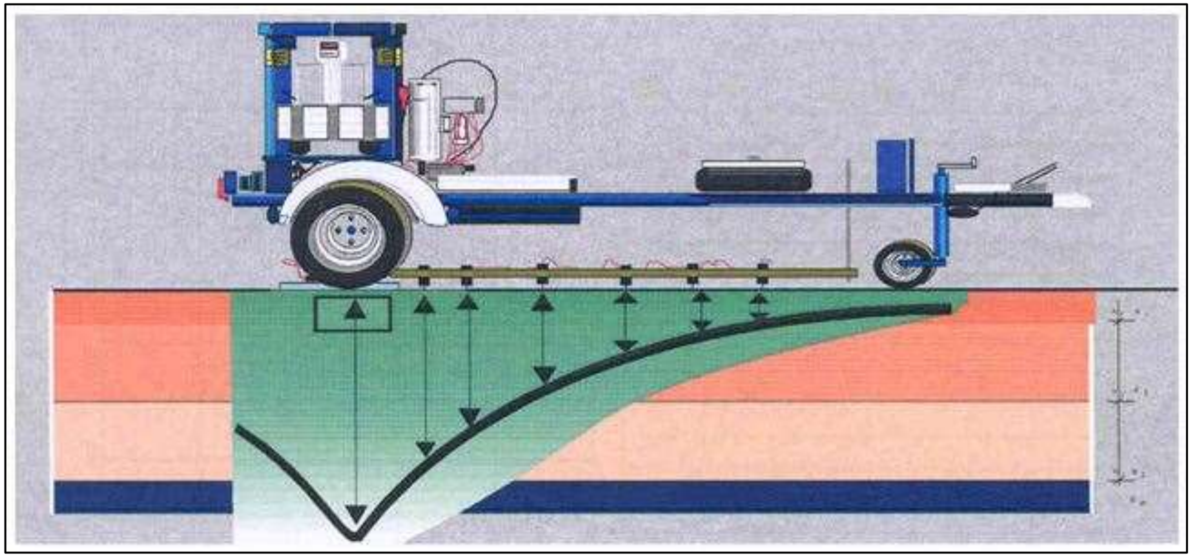
M_R= Subgrade Modulus

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

M_R = subgrade resilient modulus (in psi)

- **FWD Field Data or Historical Data**
- **Typical NDDOT Design – 4,000psi to 7,000psi**



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Flexible Pavement Design

NDDOT Approach Summary:

- **Traffic**
  - **ESALs –** ***Counts & Classifications of Vehicles***
  - **Estimation of Growth Rate –** ***Predicting Future Corridor Usage***

- **Pavement Structure**
  - **Subgrade Strength –** ***FWD / Field Data Analysis***
  - **Existing Section** ***- Field Investigation or Historical Data***
  - **Design Reliability –** ***Highway Performance Class System***
  - **Materials –** ***Structural Coefficients***

- **Bituminous Recommendation**
  - **Based on Project Type and ESALs –** ***Pavement Design***

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Questions?

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