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DESIGN MANUAL

FLEXIBLE PAVEMENT DESIGN

Baltimore County
Department of Public Works Design Manual

Flexible Pavement Design Standards

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FLEXIBLE PAVEMENT DESIGN

I. INTRODUCTION

The objective of this Section is to provide a specific design method to determine paving thickness for Baltimore County roads. To provide a more uniform approach and eliminate the poor performance of under-designed sections or the unnecessary expense of overly thick sections, it is necessary to provide one standard method.

This design procedure is based on the AASHTO Design of Pavement Structures –1993. Since the AASHTO guide was developed for flexible as well as rigid paving and for roads from small rural to highly traveled interstates it was decided that it would be more convenient and consistent to dispense with criteria and procedures that are not considered pertinent to the types of roadways that will be constructed and used in Baltimore County. The standardization of some of the variables built into the AASHTO design guide will keep designs consistent and simple. Those standardized values are:

- % Reliability,
- Overall Standard Deviation,
- Truck ESAL Factors,
- Design Serviceability,
- Layer Coefficient Factor and
- Drainage Coefficient Factor.

This guide is structured in a step-by-step approach. The design criteria are broken into seven categories: 1) % Reliability 2) Overall Standard Deviation 3) ESALs- Equivalent Single Axle Load, 4) Soil Resilient Modulus, 5) Design Serviceability Loss, 6) Design Structural Number, 7) Layer Coefficients and Drainage Coefficient Factors. Each of these categories is explained in the appendix. Soil modulus and ESALs will have to be determined based on specific site criteria.

II. DESIGN PROCEDURES

The majority of the Design Factors have been standardized for use in this design manual. Those standardized factors are as follows:

DESIGN FACTORS

% Reliability	**80%**
Standard Deviation	**0.49**
Initial Serviceability	**4.2**
Terminal Serviceability	**2.2**
Design Serviceability Loss	**2.0**
Truck ESAL Factor	**See appendix page iii**
Layer Coefficients HMA Surface HMA Base Stone Base	 **0.44** **0.34** **0.14**
Drainage Coefficient	**1.0**

The two major variables to be determined are ESALs and Resilient Modulus that vary for each project. These are determined in steps 1 and 2. When determining Resilient Modulus (Step 2) particular attention shall be paid to the method spelled out in Appendix page iv, "Subgrade Soil Resilient Modulus", to obtain CBR values to be used for the site.

Step 1. Determine Equivalent Single Axle Loads (ESALs) (see appendix page i)

* If truck classifications are available, multiply the number of trucks by the appropriate truck factor. Do this for all truck classifications. These products are added together and the sum is multiplied by: Growth Factor, 365 days, Lane Distribution Factor, and Directional Factor to find Design ESAL.

* If truck classifications are not provided, use a truck factor of 0.50 multiplied by the number of significant trucks. This product is then multiplied by Growth Factor, 365 days, Lane Distribution Factor, and Directional Factor to find Design ESAL.

Step 2. Determine Subgrade Soil Support. If CBR test results are used, convert data to Resilient Modulus. (M_R = 1500 x CBR) (see appendix page iv)

Step 3. Enter data into nomograph to determine Structural Number. Note: % Reliability and Standard Deviation are already plotted on Sample Nomograph (see appendix page vi).

Step 4. Using the provided Layer Coefficients and Drainage Coefficients, determine pavement component thickness. (see appendix page v) Note: Minimum and Maximum layer thickness must be adhered to (see following table).

Road Component Thickness Table

MATERIAL	DESIGN USE	MIN LIFT	DESIRED LIFT	MAX LIFT
HMA SUPERPAVE 4.75mm	SURFACE	0.5"	0.75"	0.75"
HMA SUPERPAVE 9.5mm	SURFACE	1.0"	1.5"	2.0"
HMA SUPERPAVE 12.5mm	SURFACE/BASE	1.5"	2.0"	2.5"
HMA SUPERPAVE 19.0mm	BASE	2.0"	2.5"	4.0"
HMA SUPERPAVE 25.0mm	BASE	3.0"	3.5"	5.0"
HMA SUPERPAVE 37.5mm	BASE	4.0"	5.0"	6.5"
GRADED AGGREGATE BASE	STONE BASE	3.0"	6.0"	6.0"
CR-6	SUB-BASE	3.0"	6.0"	6.0"

EXAMPLE #1

Given: Two Lane Urban Minor Collector

% Reliability	80%*****
Standard Deviation	.49*****
Design Life	20 years
Annual Growth Rate	2%
Average Daily Traffic (ADT)	10,202
% Significant Trucks	5%
Truck Factor for Total Trucks	0.50*****
Directional Distribution Factor	50%
Soil Support CBR	5.0
Design Serviceability Loss ΔPSI	2.0*****
Drainage Factor	1.0*****

***** Standardized Values

Step 1- ESAL Determination:

10,202(ADT) x .05(%trucks) = 510 Initial Significant Trucks

510 x 24.30(Growth Factor)* x 365(Days) x 0.50 (Truck Factor) x 0.50 (Directional Distribution Factor) =

1.13×10^6 Design ESAL

*****See Traffic Growth Factor Table, Appendix page ii.

Step 2- Resilient Modulus:

M_R = 1500 x CBR

5 x 1500 = 7500

M_R = 7500

Step 3- Determine Structural Number from nomograph (* See Nomograph Example #1)

Structural Number SN (from nomograph):

Design SN = 3.2

Step 4- Selection of Layer Thickness:

$SN = a_1D_1 + a_2D_2M_2 + a_3D_3M_3$, where

a_1, a_2, a_3 -- Layer coefficients for Surface, Base, and Stone Base respectively

D_1, D_2, D_3 – Thickness in inches of Surface, Base, and Stone Base respectively.

M_2, M_3 – Drainage coefficients for Surface, Base, and Stone Base respectively

SN = (.44 x 1.5”) + (.34 x 4.0”x 1.0) + (.14 x 8”x 1.0)

SN = .66 + 1.36 + 1.12

SN = 3.14

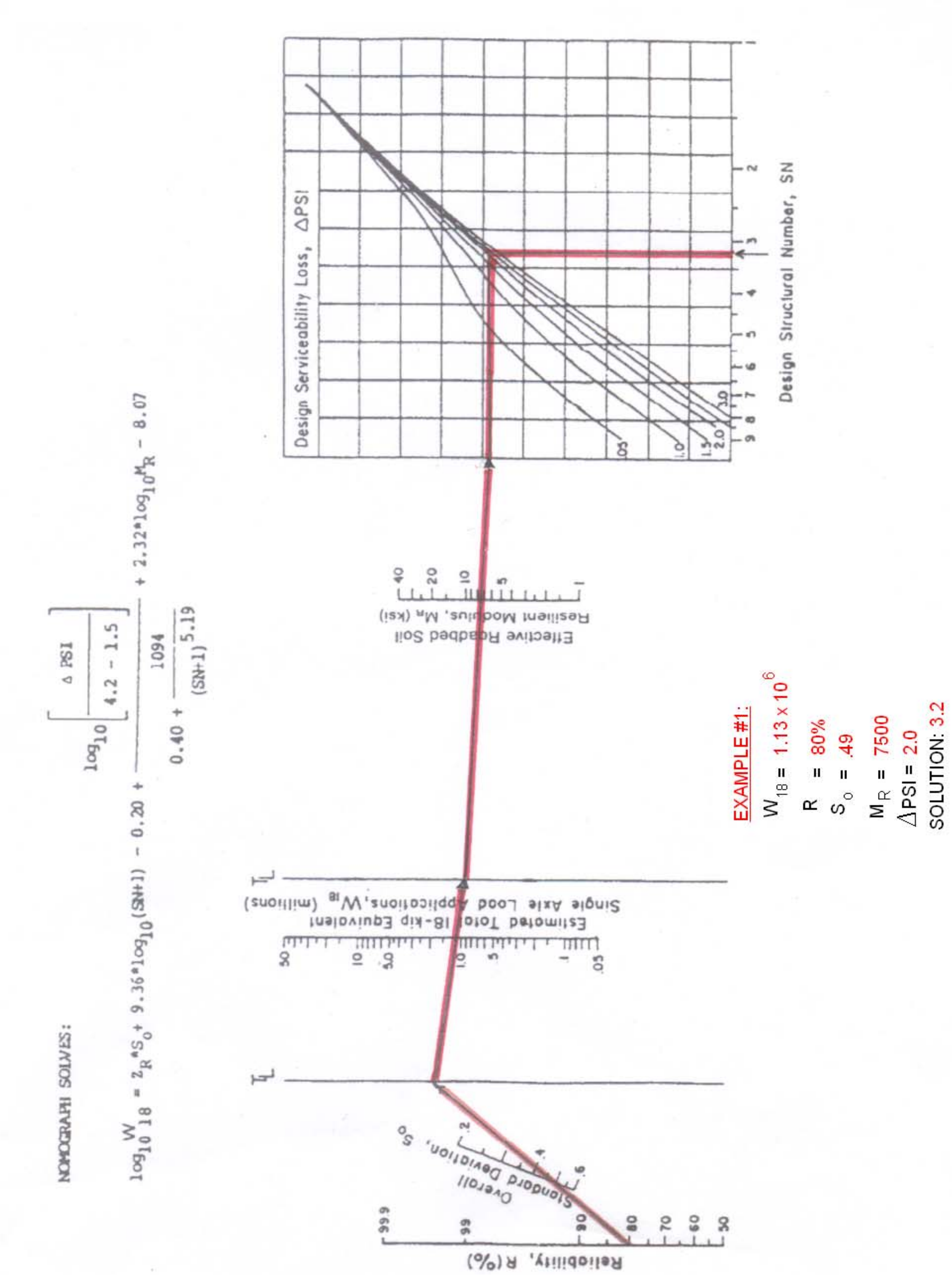
Paving Section Solution:

Surface Course – 1.5”

Base Course - 4.0”

Stone Base - 10”

EXAMPLE #1 NOMOGRAPH



EXAMPLE #2

Given: Four Lane Urban Collector with medium to heavy industry

% Reliability	80%*****
Standard Deviation	.49*****
Design Life	20 years
Annual Growth Rate	2%
Average Daily Traffic (ADT)	13,500
Buses	160******
2 Axle 6 Tire Trucks	305******
3 Axle Single Unit Trucks	225******
5 Axle Single Trailer Trucks	210******
Lane Distribution Factor	90%
Directional Distribution Factor	50%
Soil Support CBR	5.0
Design Serviceability Loss ΔPSI	2.0*****
Drainage Factor	1.0*****

***** Standardized Values
****** See Chart in Appendix page iii

Step 1- ESAL Determination:

Buses:
160 x 0.57 = 91.20
2 Axle 6 Tire Trucks:
305 x 0.26 = 79.30
3 Axle Single Unit Trucks:
225 x 0.42 = 94.50
5 Axle Single Trailer Trucks:
210 x 1.20 = 252

91.20 + 79.30 + 94.50 + 252 = 517 Initial Daily Esal

517 x 24.30 (Growth Factor)* x 365 (Days) x 0.90 (Lane Distribution Factor) x 0.50 (Directional Distribution Factor) =

2.10 x 10^6 Design ESAL

* See Traffic Growth Factor Table Appendix page ii

Step 2- Resilient Modulus:

M_R = 1500 x CBR = 5 x 1500 = 7500

M_R = 7500

* See Nomograph Example #2

Step 3- Determine Structural Number SN (from nomograph):

Design SN = 3.65

Step 4- Selection of Layer Thickness:

$SN = a_1D_1 + a_2D_2M_2 + a_3D_3M_3$

$a_{1,}\ a_{2,}\ a_3$ - Layer coefficients for Surface, Base, and Stone Base respectively

$D_{1,}\ D_{2,}\ D_3$ – Thickness in inches of Surface, Base, and Stone Base respectively.

M_2, M_3 – Drainage coefficients for Surface, Base, and Stone Base respectively.

SN = (.44 x 1.5”) + (.34 x 5.5”x 1.0) + (.14 x 8.0”x 1.0)

SN = .66 + 1.87 + 1.12

SN = 3.65

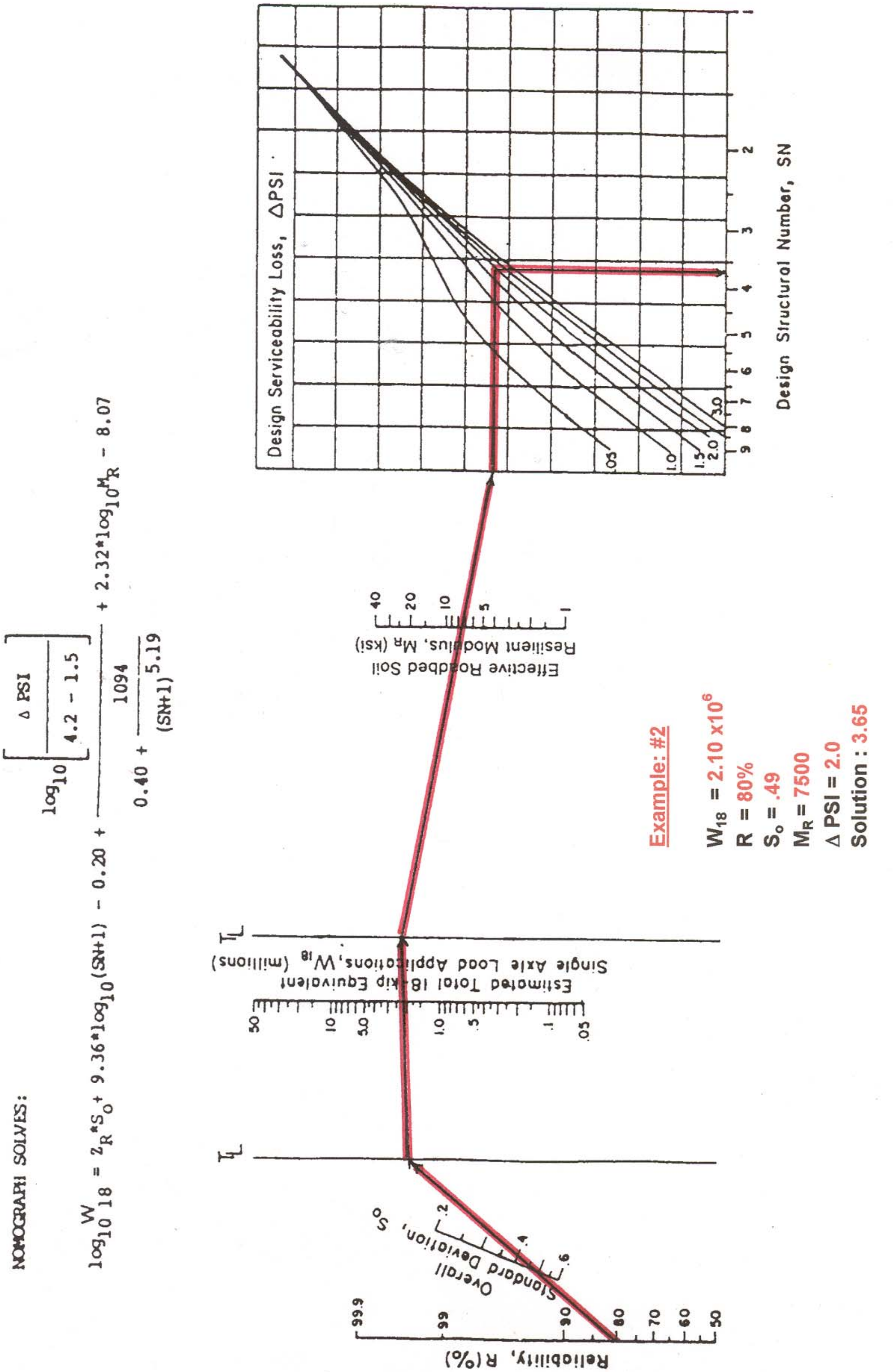
Paving Section Solution:

Surface Course – 1.5”

Base Course - 5.5”

Stone Base - 8.0”

EXAMPLE #2 NOMOGRAPH



APPENDIX

% RELIABILITY

The AASHTO Design Guide defines reliability, as "The probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period." The design period refers to the performance period or period of time elapsed as initial pavement structure deteriorates from its initial to its terminal serviceability. The reliability design factor accounts for variations in both traffic predictions and the performance prediction. This provides a level of assurance that the pavement section will perform to expectations throughout its design period.

For the ranges given by AASHTO a reliability factor of 80% would provide adequate assurance of a successful paving section for the types of roadways in Baltimore County.

STANDARD DEVIATION

According to the AASHTO Guide for Design of Pavement Structures, the estimated overall standard deviation for cases where the variance of projected future traffic is considered will be **0.49** for flexible paving.

EQUIVALENT SINGLE AXLE LOADS (ESALS)

ESAL determination will vary from project to project due to different traffic data. Some of the inputs used to determine ESALs will be constant. Average Daily Traffic (ADT) will be provided by Baltimore County Department of Public Works. Growth Factors (determined on percent growth) will be obtained from the following table.

Traffic Growth Factors*

Analysis Period Years (n)	Annual Growth Rate, Percent (g) 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

*Factor = $\frac{(1 + g)^n - 1}{g}$, where g = $\frac{rate}{100}$ and is not zero. If annual growth rate is zero, the growth factor is equal to the analysis period.

NOTE: The above growth factors multiplied by the first year traffic estimate will give the total volume of traffic expected during the analysis period.

This table is found in appendix D of the AASHTO *Guide for Design of Pavement Structures*.

Table 2: FHWA Vehicle Classification (from FHWA, 2001)[1]

Class	Type	Description	Typical ESALs per Vehicle[2]
4	Buses	All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. All two-axle, four-tire single unit vehicles. Modified buses should be considered to be a truck and be appropriately classified.	**0.57**
5	Two-Axle, Six-Tire, Single Unit Trucks	All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., having two axles and dual rear wheels.	**0.26**
6	Three-Axle Single Unit Trucks	All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., having three axles.	**0.42**
7	Four or More Axle Single Unit Trucks	All trucks on a single frame with four or more axles.	**0.42**
8	Four or Less Axle Single Trailer Trucks	All vehicles with four or less axles consisting of two units, one of which is a tractor or straight truck power unit.	**0.30**
9	Five-Axle Single Trailer Trucks	All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.	**1.20**
10	Six or More Axle Single Trailer Trucks	All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.	**0.93**
11	Five or Less Axle Multi-Trailer Trucks	All vehicles with five or less axles consisting of three or more units, one of which is a tractor or straight truck power unit.	**0.82**
12	Six-Axle Multi-Trailer Trucks	All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.	**1.06**
13	Seven or More Axle Multi-Trailer Trucks	All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.	**1.39**

Note 1: In reporting information on trucks the following criteria should used:

1. Truck tractor units traveling without a trailer will be considered single unit trucks.
2. A truck tractor unit pulling other such units in a "saddle mount" configuration will be considered as one single unit truck and will be defined only by the axles on the pulling unit.
3. Vehicles shall be defined by the number of axles in contact with the roadway. Therefore, "floating" axles are counted only when in the down position.
4. The term "trailer" includes both semi- and full trailers.

Note 2: Based on the overall ESAL per vehicle class for 10 weigh-in-motion (WIM) sites averaged over a one-year period. The averaging method treats all pavements the same (i.e., no separate LEFs for flexible and rigid pavements).

If a traffic classification breakdown is not included with ADT counts provided by Baltimore County Department of Public Works then an overall truck factor of **0.50** will be used with % trucks to determine ESALs.

DIRECTIONAL AND LANE DISTRIBUTION FACTORS

The Directional Distribution Factor is a ratio that accounts for the distribution of ESAL units by Direction. Generally **50** percent is used for most roadways. However there are situations where heavier traffic may be moving in one direction changing the ratio from as low as 3 percent to as high as 7 percent depending upon the direction of heavier traffic.
The Lane Distribution Factor is a ratio that accounts for the distribution of traffic when two or more lanes are designed in one direction. The following chart taken from the AASHTO Guide for Design of Pavement Structures may be used as a reference.

# of Lanes in Each Direction	% of 18-kip ESAL in Design Lane
1	**100**
2	**80-100**
3	**60-80**
4	**50-75**

SUBGRADE SOIL RESILIENT MODULUS M_R

The AASHTO Guide for Design of Pavement Structures bases it's design procedures on sub grade strength reported in terms of resilient modulus (M_R). California Bearing Ratio (CBR) can be used to assess soil strength but all analysis, and designs will be done in terms of resilient modulus for the soil subgrade. A conversion from CBR to resilient modulus can be used as follows:

$$M_R = 1500 \times CBR$$

The minimum frequency for resilient modulus testing will be 1 per 1000' of roadway, and every soil change. If four or less tests are taken, the average value is used. If five or more tests are taken, disregard the highest and lowest values and average the remaining test results. Areas with low test values (less than a resilient modulus of 6000 psi) shall be defined. These areas shall call for undercutting and or stabilization of the subgrade. These treated areas shall be improved to obtain a resilient modulus greater than or equal to the average test value for the project. The United States Department of Agriculture's Soil Survey for Baltimore County should be referenced as an aid to help determine if problem soils will be encountered during the project. When soil tests results are not available a resilient modulus of **6000 psi** can be used. However, this should be avoided whenever possible. Obviously, direct and accurate test data will help ensure a more reliable, durable and cost effective section. All sampling and material testing should be performed by an AASHTO accredited laboratory.

DESIGN SEVICEABILITY LOSS (Δ PSI)

The serviceability of a given pavement is its ability to provide adequate support and a satisfactory ride at any specific time. Performance of a pavement may be described by observations of its serviceability at the completion of construction and at the point of rehabilitation. For the type of roads to be designed in Baltimore County an Initial Serviceability (P_o) of **4.2** would be adequate. Terminal Serviceability (P_t) is the lowest index allowed before rehabilitation is necessary. The assumed P_t used will be **2.2.**The following equation is used to find Design Serviceability Loss (Δ PSI).

$$\Delta PSI = P_o - P_t$$

The total change in serviceability index or Design Serviceability Loss (Δ PSI) will be **2.0**.

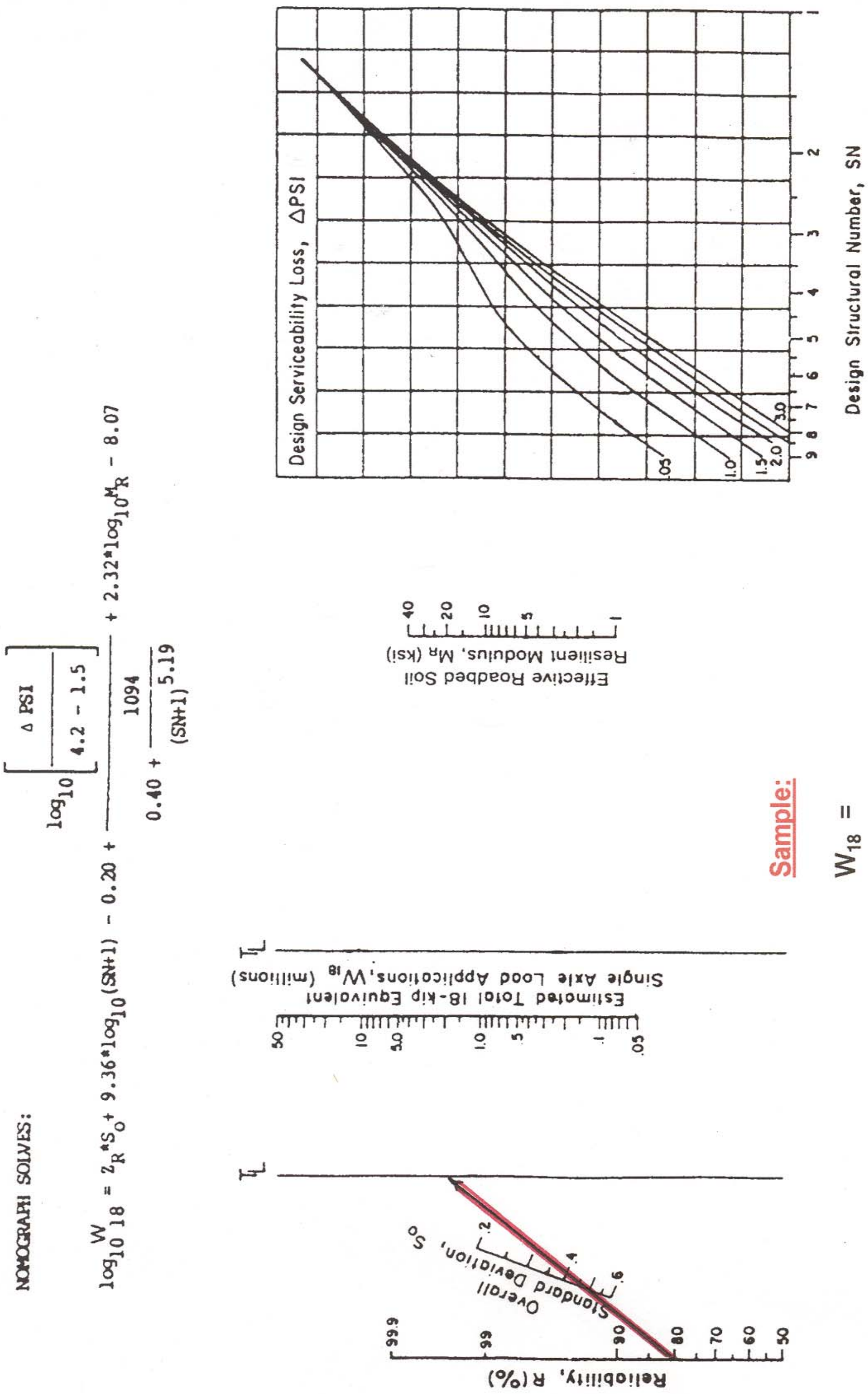
STRUCTURAL NUMBER SN

The previous design factors will be used in the Design Chart for Flexible Paving (found on the next page) to determine structural number. This nomograph was obtained from the AASHTO *Guide for Design of Structural Pavements* on page II-32.

LAYER AND DRAINAGE COEFFICIENT FACTORS

The following are the layer coefficients to be used for the components of the paving section: HMA Surface Paving Course – **0.44**; HMA Base Paving Course **– 0.34**; Stone Base - **0.14**. Drainage coefficient factors of **1.0** will be used as a worst-case scenario.

DESIGN CHART FOR FLEXIBLE PAVING



Sample:

W_{18} =

R =

S_o =

M_R =

Δ PSI =

Solution :