DESIGN GUIDE
FOR FLEXIBLE PAVEMENT

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INTRODUCTION

Competent design of hot-mix asphalt (flexible) pavements provides a system that is stable, durable, and cost-effective. The primary principle that forms the basis for flexible pavements is that the vehicular loads can be dissipated through successive layers of properly engineered materials. The success of such design is based on: i) an evaluations of the subgrade soil, ii) the relative load support value of pavement components, and iii) the magnitude and repetitions of traffic loads. The design criteria outlined here provide a user-friendly pavement design method for new local, low-volume residential roadways. This procedure is localized for Carroll County conditions, and considers the factors mentioned above. There are recommendations included to address new commercial /industrial roadways for light industrial developments.

In this procedure, the subgrade soil is classified on the basis of laboratory resilient modulus or California Bearing Ratio (CBR) testing. Traffic level in terms of Average Daily Traffic (2-way) and percent trucks is then determined from available planning information. Once the subgrade support value and traffic classifications are known, the next step is to pick the appropriate Structural Number (SN) from the charts provided in this design guide. The pavement structure thickness is then calculated using the individual layer structural coefficients and minimum layer thickness criteria.

DEFINITIONS

The following definitions apply to the terms and acronyms in this specification. Other definitions may exist for these terms, but as they are used in this guide, the following definitions apply:

AASHTO
American Association of State Highway and Transportation Officials

AASHTO Guide
AASHTO Guide for Design of Pavement Structures published in 1993.

ADT
Average Daily Traffic volume, both directions.

ASTM
The American Society for Testing and Materials

Base or Base Course
The layer of material directly beneath the hot mix asphalt surface layer. The base may be composed of asphalt, crushed stone, or cement treated aggregate.

California Bearing Ratio (CBR)
A laboratory test in which a standard piston is driven into a compacted soil specimen. The force required to drive the piston 0.1” is compared to a standard value of 1000 psi for crushed California limestone. The result expressed as a percentage of the standard value.

County
Authorized representatives of Carroll County government.

Design CBR
The Design CBR is the average CBR value for the subgrade soil.

Engineer
The professionally licensed firm or individual providing the pavement design.

Hot Mix Asphalt
Hot Mix Asphalt (HMA) is a mixture of asphalt cement and aggregate, produced at a batch or drum mixing facility that must be mixed, spread, and compacted at an elevated temperature.

Owner/Developer
The person, persons, or company who are responsible for ensuring that construction and/or proposed construction on a given site complies with appropriate County policies and regulations.

Resilient Modulus
Resilient modulus is the primary material property that is used to characterize the roadbed soil for the design of flexible pavements as per the recommendations of AASHTO Guide.

Section
Section, or pavement system, is the in-place total thickness of subbase, base course and surface course, placed in layers on a subgrade to support and distribute the traffic load to the roadbed.

Subbase
That layer of the pavement system immediately below the base and immediately above the subgrade. Subbases are often composed of aggregates, gravel, or cement treated materials.

Subgrade
The layer of soil which supports the pavement system. The subgrade soil may be a naturally deposited material or it may be fill material borrowed from another source.

Surface Course
The uppermost layer of the pavement system, composed of hot mix asphalt.

1.0 DESIGN CONSIDERATIONS

1.1 EVALUATION OF THE SUBGRADE SOIL

The support value of approved subgrade soil (see Materials Section for subgrade soil specifications) is classified based on the resilient modulus or on the average California Bearing Ratio (CBR) for the subgrade soil. If four or fewer tests are conducted, use the average value; if 5 or more tests are performed, eliminate the high and low values and average the remaining test results.

Table 1 - Support Value for Subgrade Soils

Effective Resilient Modulus (psi)	CBR	Relative Quality of Roadbed Soil
8,000	> 5.3	Very Good
7,000	4.7	Good
6,000	4.0	Good
5,000	3.3	Fair
4,000	2.7	Fair
3,000	2.0	Poor
2,000	1.3	Very Poor

This correlation (Resilient Modulus = 1,500 x CBR) is based on subgrade soils tested in accordance with either AASHTO Test Method T-307 (Resilient Modulus) or AASHTO Test Method T-193 (soaked CBR).

1.2 PAVEMENT COMPONENTS

Each of the pavement components above the subgrade adds to the overall support provided by the pavement system. By quantifying the relative values of pavement components, various design alternatives may be examined and compared. Common components of the flexible pavement system include HMA surface course, HMA base course, graded aggregate subbase, and other materials. Requirements for each of these materials are included in the Materials Section.

1.3 TRAFFIC VOLUME

A critical factor to be considered in the design of flexible pavements is the anticipated traffic volume and the magnitude of the loads it will impose on the pavement system. For the purposes of this guide, a 20-year design life has been assumed. Therefore, traffic levels used in the design process should be the total anticipated traffic for the following 20-year period. Figures are presented to provide the design number of Equivalent Single Axle Loads (ESAL) for combinations of ADT and truck percentage. Traffic levels exceeding those shown in the figures are beyond the scope of this guide and the designer is referred to the AASHTO Guide, Part II, Chapter 3, to perform the design.

1.4 DESIGN PARAMETERS

The AASHTO flexible pavement design process relies on a variety of design inputs to produce the required structural number sufficient to carry the design traffic. These parameters are described in the following paragraphs and the values used to develop the charts in this design guide are also provided in Table 2.

Reliability Level - The reliability levels for residential and other low volume roads in Carroll County is assumed to be 80%, based on recommendations in the AASHTO Guide. Depending on the accuracy of the predicted future traffic the reliability value can be varied. The charts used in this guide are based on 80% reliability.

Standard Deviation - A standard deviation of 0.49 was used for the flexible pavement design, to account for the effect on performance of construction and materials related variability in the finished pavement structure.

Drainage Coefficient - A drainage coefficient of 1.0 was used for the flexible pavement design as a worst case scenario as recommended by the AASHTO Design Guide.

Initial and Terminal Serviceability Levels - The initial serviceability level used for the flexible design was 4.2 as recommended by AASHTO. This value is consistent with smooth pavement surfaces exhibiting International Roughness Index values less than approximately 50 inches per mile or Profilograph readings of 2 inches per mile or less. The terminal serviceability level was set at 2.0 indicating an IRI somewhat greater than approximately 225 inches per mile. This is considered somewhat rough but an acceptable level of serviceability for these roadways. Major maintenance and rehabilitation is expected at this level of serviceability.

Layer Coefficients for Hot Mix Asphalt - For the HMA surface mix, a layer coefficient of 0.44 is recommended. HMA base course layers should have a coefficient of 0.34. Layer coefficients of 0.14 and 0.11 for granular base and granular subbase materials, respectively, are recommended by AASHTO.

Design Period - For new HMA pavement, a design life of 20 years was used for the design guide. In this manual, service life includes an allowance for construction traffic in the first 5 years. The construction traffic loading is calculated by using a relatively high truck ESAL factor while maintaining the planned ADT and truck percentage. After year 5 lowering the truck ESAL factor for years 6 through 20 reduces the truck loading. The effect of this is to account for the high loading during construction, providing sufficient pavement structure to accommodate the loading, while not over-designing the roadway. The ESAL values shown in the figures incorporate the adjustment for construction traffic. The users need only use ADT and truck percent; no calculation of the effect of construction traffic is needed.

Table 2 summarizes the parameters used in this flexible pavement design guide.

Table 2 – Design Parameters for Carroll County

Reliability	80%
Overall Standard Deviation	0.49
Drainage Coefficient, *m*	1.0
Initial Serviceability	4.2
Terminal Serviceability	2.0
Layer Coefficient - HMA Surface, a_1 HMA Base Course, a_2	 0.44 0.34
Layer Coefficient - Granular Base Material, a_3	0.14
Layer Coefficient - Granular Subbase, a_4	0.11

2.0 PROCEDURE

The design process follows these steps:

1. Determine the resilient modulus for the roadbed soil from laboratory tests, referring to Table 1 if CBR testing is performed.
2. Using planning data and estimates, determine the ADT and percent trucks (T%).
3. Determine the design ESALs from Figure 1 using the ADT and T%. (Figure 3 is provided for low volume roads and Figure 4 for Commercial/Industrial).
4. Determine the required SN by entering Figure 2 using the design resilient modulus (interpolating for values between those depicted) and design ESALs. (Figure B.2a is provided for low volume roads).
5. Choose appropriate layer material coefficients and then combination of pavement layer thicknesses to meet the required SN, adhering to minimum and maximum layer thickness requirements.
6. If the traffic levels exceed the values provided in this design manual, perform pavement design based on the criteria of AASHTO Guide.

Note: Each of the design charts is duplicated in Appendix B using the same index number preceded by "B", e.g. Figure B.2 is a reprint of Figure 2.

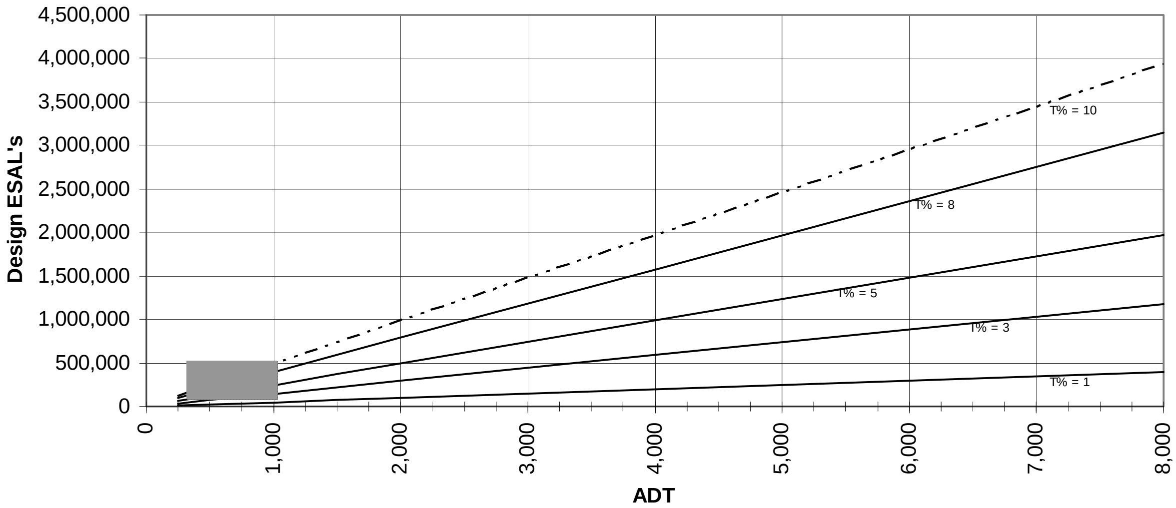

Figure 1 - Design ESALs from ADT and Truck Percentage, T%

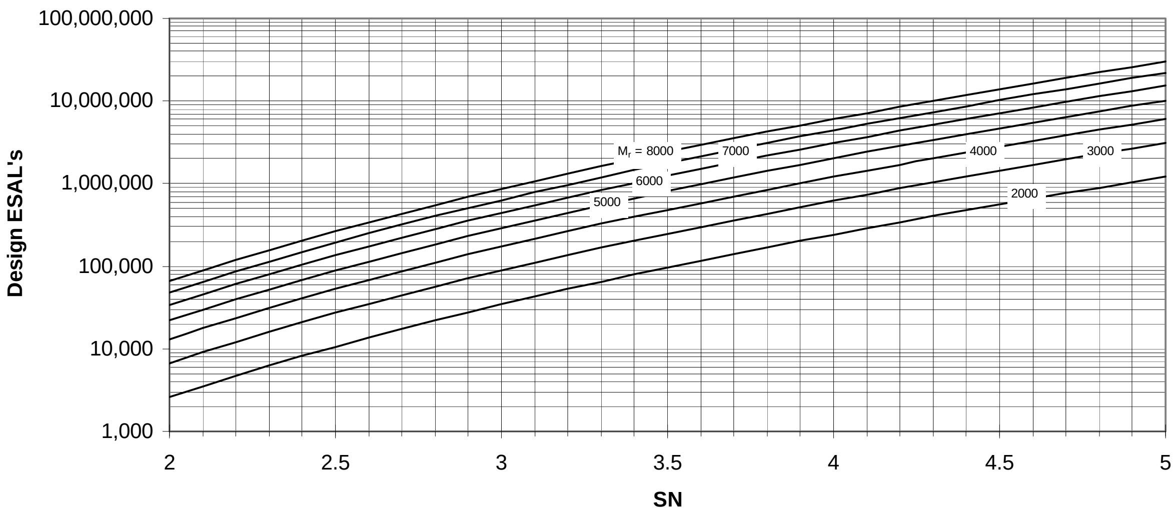

Figure 2 - Structural Number Required from Design ESALs and Subgrade Resilient Modulus (M_r)

Note: These charts are presented in Appendix B in a larger format for ease of use.

Figure 3 is provided for design of roadways having ADT less than 1000. This is a scaled up portion of Figure 1 for ease of use. This figure is also provided in large format in the Appendix as Figure B.3.

Design for Commercial/Industrial pavements requires addressing higher truck percentages as well has greater average truck weights than for typical low volume and residential pavements. Figure 4 presents the relationship between design ESALs and truck percentage for Commercial/Industrial roadways. It uses a higher truck factor (ESAL per truck) than residential as well as providing a much greater range of truck percentages. Design ESALs from Figure 4 are used to determine the SN required (Figure 2).

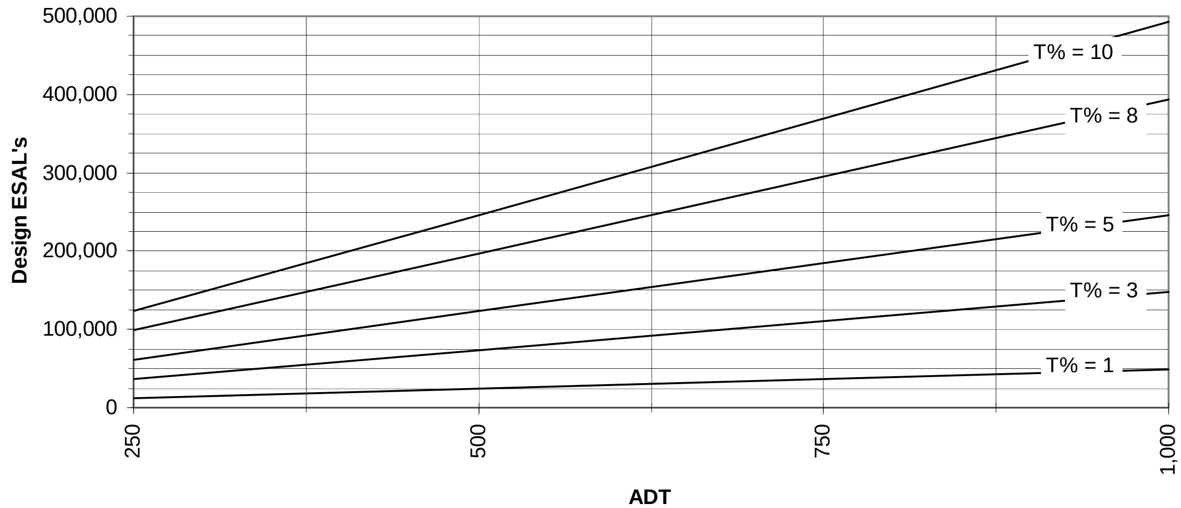

Figure 3 - Design ESALs for ADT < 1000

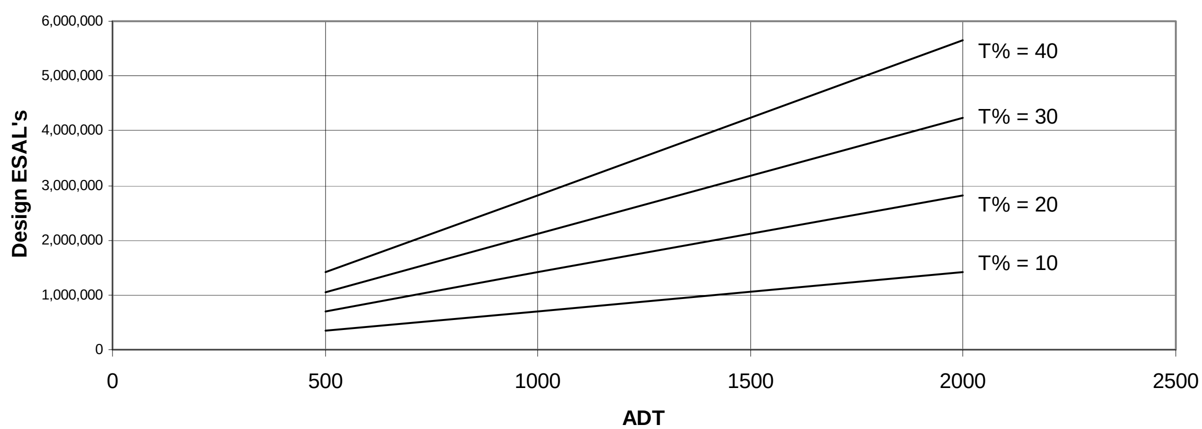

Figure 4 - Design ESALs for Commercial/Industrial Roads

3.0 DETERMINATION OF PAVEMENT SECTION

The flexible pavement section usually consists of varying thicknesses of hot-mix asphalt surface and base courses, a crushed stone subbase, and an approved subgrade soil. In order to accommodate construction and provide long-term acceptable performance, the following guidelines have been established for the thickness of pavement components:

<table>
<tr><th>Layer</th><th>Minimum</th><th>Maximum</th></tr>
<tr><td>Aggregate Subbase</td><td>4 inches</td><td></td></tr>
<tr><td>Aggregate Base</td><td>6 inches</td><td></td></tr>
<tr><td>Hot Mix Asphalt Base (compacted) over Aggregate Subbase</td><td colspan="2" rowspan="3">Mix specific - See requirements in Appendix A Section 3, Table 7</td></tr>
<tr><td>Per lift (compacted), Hot Mix Asphalt Base</td></tr>
<tr><td>Hot Mix Asphalt Surface (compacted)</td></tr>
</table>

3.1 GUIDELINES FOR THICKNESS OF COMPONENTS

Structural number is a function of layer thicknesses, layer coefficients, and drainage coefficients. It is computed from:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

where;

SN = Structural number of pavement

a_1, a_2, a_3 = layer coefficient for the surface, base and subbase, respectively

D_1, D_2, D_3 = thicknesses of the surface, base and subbase, respectively

m_2, m_3 = drainage coefficient of base and subbase course, respectively

The layer coefficients a_1, a_2, a_3 are a measure of the relative ability of a unit thickness of a given material to function as a structural component of the pavement. Layer coefficients may be determined from correlations with material properties. The layer coefficients in Table 2 are recommended for Carroll County conditions.

The drainage coefficients m_2, m_3 are applied to granular bases and subbases to modify the layer coefficients on account of moisture availability and quality of drainage in these materials. Given the type of roadways addressed in this guide, we recommend using a drainage coefficient of 1.0 to ensure a degree of conservatism in final cross section thickness.

3.2 THICKNESS CALCULATIONS

Based on the subgrade category and traffic (ESALs), the appropriate Structural Number (SN) is chosen from Figure 2. Based on the required SN many combinations of layer thicknesses are acceptable. The designer must rely on minimum layer thickness requirements, managing material costs and construction and maintenance constraints to arrive at an acceptable pavement cross-section.

4.0 UNDERDRAINS AND SUBGRADE DRAINS

Underdrains may be necessary in areas of natural springs, high seasonal groundwater, cuts, or in other areas, at the direction of the County. All underdrains, consisting of underdrain pipe, outlet pipe, aggregate backfill, geotextile and concrete will be installed in accordance with Section 306 of the latest Maryland State Highway Administration's Standard Specifications for Construction and Materials and all applicable revisions.

Permanent Subgrade Drains, consisting of pipe, outlet pipe, aggregate backfill, and geotextile, shall be constructed in accordance with Plate 43-A of the Carroll County Road and Storm Drain Design Manual, unless otherwise directed by the County. In those cases, the County may allow construction to be in accordance with Section 306 of the Maryland State Highway Administration's Standard Specifications for Construction and Materials and all applicable revisions.

The design of subgrade drains shall be submitted to the County for review and approval as part of the preliminary plan submittals.

5.0 SUBMITTALS

Minimum requirements for the field sampling and testing for new roads are contained in the Appendix. The proposed boring location/sampling plan must be submitted to the County for review and approval. Upon approval of the boring location/sampling plan, the following additional information shall be submitted to the County for review and approval:

1. A test report of subgrade soils including sample location and laboratory test results.
2. The proposed pavement design including method used and estimated traffic counts.
3. Design of subgrade drains, and underdrains, if required.
4. Documentation that pavement materials comply with referenced specifications.

APPENDIX A

PAVEMENT MATERIALS SPECIFICATIONS

INTRODUCTION

The performance of any pavement system depends not only upon an adequate design, but also on materials of known and predictable engineering properties. In order to insure that pavement materials perform adequately, appropriate testing must be performed and documented. All pavement materials (subbase, graded aggregate base, hot mix asphalt) must be supplied by a producer approved for MD State Highway Administration (SHA) work. Mix designs for hot mix asphalt must be approved by the MD SHA Regional Laboratory in control of the plant location area. Graded aggregate base must have MD SHA approval along with job mix formula information showing gradation, maximum dry density, and optimum moisture content.

1.0 SUBGRADE SOIL

All soils that are anticipated for use as pavement subgrade must be tested in order to establish the acceptability of the soils and to determine the appropriate pavement section. The requirement for sampling and testing includes soils from cut areas which are anticipated for later use as subgrade fill. A certified copy of laboratory test results of all subgrade soils shall be submitted to the County for review and approval during the preliminary plan phase of the work. The following sections outline test spacing, methodology, and criteria for acceptance for subgrade soils.

1.1 TEST SPACING

Subgrade samples will be taken from a depth of 0-3 feet below the design elevation at the approximate centerline of the roadway. Intervals between soil samples shall not exceed 500 feet or wherever there is an apparent soil change; two samples minimum per road, or as directed by the County. Samples taken at roadway intersections may be used for both roadways providing the requirements for spacing are met. In cases where a proposed road intersects an existing road, the first sample shall be taken within 50 feet from the center of the existing road. All samples must be identified by Road Name, Station Number, Offset from Centerline and Depth (below design elevation). Test locations given here are minimum requirements; design engineer(s) are responsible to familiarize themselves with site conditions and to conduct whatever additional testing they determine necessary in order to properly design the pavement system.

1.2 TEST REQUIREMENTS AND SPECIFICATIONS

Subgrade soils shall be free of trash, debris, organic material or other deleterious materials. The top two feet of soil shall not contain gravel larger than 3 inches. Additionally, all subgrade soils shall meet the requirements shown in Table 3.

Table 3 - Subgrade Soil Specifications

Test (AASHTO Test Method)	Specification
Liquid Limit (T-89)	< 45
Plastic Limit (T-90)	None
Plasticity Index (T-90)	< 20
Washed Gradation (T-88)	100% < 3”*
Soil Classification (Unified Method)	All except CH, MH, OH, Pt
Organic Content (T-267)	< 3 %
Moisture Density Relationship (T-180)	> 100 pcf dry density
California Bearing Ratio, Soaked (T-193)	> 3.0
Resilient Modulus (T-307)	> 4,000 psi

* For top 2 feet of subgrade soil

1.3 UNACCEPTABLE SUBGRADE SOIL

When subgrade soils do not meet the requirements set forth in this specification, the top two feet of such soil shall be undercut, removed and replaced with acceptable material. If the removal and replacement of unacceptable subgrade soil is not feasible, other methods may be employed to improve its engineering performance. Such methods may be pursued only with the prior permission of the County.

Some unacceptable subgrade soils can be chemically altered using lime, Portland cement or other materials. In order to be approved by the County, any program for treating or altering subgrade soil shall be documented by a Soils Engineer, including appropriate laboratory test results and submitted to the County. Evaluation and approval by the County of such treatments shall be handled on a case-by-case basis.

2.0 BASE AND SUBBASE MATERIALS

Graded aggregates for base and subbase construction of flexible pavements shall meet the requirements of Section 901 of the latest version of Maryland State Highway Administration’s Standard Specifications for Construction and Materials and all applicable revisions. The Owner/Developer must supply the County with material source information and mix designs for subbase, graded aggregate base, and hot mix asphalt a minimum of two weeks prior to use.

Table 4 – Aggregate Base and Subbase Specifications

Percent Passing Sieve Size	Base	Subbase
2 ½ in.		
2 in.	100	100
1 ½ in.	95-100	90-100
1 in.		
¾ in.	70-92	60-85
½ in.		
⅜ in.	50-70	40-70
No. 4	35-55	30-60
No. 10		
No. 30	12-25	10-25
No. 40		
No. 200	0-8	0-12
Plasticity Index, Max.	6	6
Sodium Sulfate Soundness, Max. % Loss	12	12
L.A. Abrasion, Max. % Loss	50	50
Flat and Elongated Particles, Max, %	15	15

3.0 HOT MIX ASPHALT

Asphalt cements and hot mix asphalt shall conform to the requirements of Section 904 of the latest version of Maryland State Highway Administration's Standard Specifications for Construction and Materials and all applicable revisions. An approved mix design for applicable materials shall be submitted to the County at least three weeks prior to paving operations.

For Carroll County roads the following guidelines are provided. The typical mixes are shown in Table 5. The compactive effort during mix design is based on the design ESALs as shown in Table 6. For the traffic volumes and loading characteristics addressed in this design guide the choice of asphalt mixes to be used in new construction is limited. Performance expectations and structural properties are presented in Section 2 of this document. Table 7 presents HMA layer thickness limits based on MDSHA experience. This guidance should be used to decide the type of surfacing and total number of lifts required to build a pavement structure.

Table 5. Performance Grade Binder Recommendations

Mix	Binder
Hot Mix Asphalt Superpave 9.5 mm for Surface	PG 64-22
Hot Mix Asphalt Superpave 12.5 mm for Surface	PG 64-22
Hot Mix Asphalt Superpave 19.0 mm, for Base	PG 64-22
Hot Mix Asphalt Superpave 25.0 mm, for Base[1]	PG 64-22
Hot Mix Asphalt Superpave 9.5 mm, for Wedge and Level	PG 64-22

[1] Not recommended for low volume residential roads

Table 6. Mix Design Compaction Level

Compaction Level	**Design ESALs** (million)
1	< 0.3
2	0.3 to < 3.0

Table 7. Lift and Layer Thickness Guidelines

Lift Thickness				Mix Size	Design Application
Minimum	Preferred	Maximum	Total Maximum		
3.0”	3.5”	4.0”	10.5”	25.0 mm	Base
2.0”	2.5”	3.0”	9.0”	19.0 mm	Base
1.5”	2.0”	2.5”	6.0”	12.5 mm	Surface
1.0”	1.5”	2.0”	3.0”	9.5 mm	Surface, Leveling

In no event shall a hot mix asphalt base course remain uncovered. If the final hot mix asphalt surface course will not be applied immediately after placement of the hot mix asphalt base course, an intermediate surface course shall be placed.

PAVEMENT DESIGN EXAMPLES

No. 1 Given: 3000 ft. roadway, estimated 500 vehicles per day. Truck Traffic is 3% of ADT. CBR values = 2.2, 1.8, 1.5, 2.5, 3.3, 1.3.

1. Design CBR = $\frac{2.2+1.8+1.5+2.5}{4} = 2$
2. Based on the CBR of 2 the resilient modulus of the subgrade soils is 3,000 psi. (Table 1)
3. From Figure B.3 (ADT < 1,000), the design ESALs are 75,000
4. From Figure B.2a, the required SN is 2.92
5. Pick the appropriate values for layer coefficients from Table 2

The following alternative could be used:

Pavement Layer	D, in	Layer Coeff.	a_iD_i
Asphalt Surface	1.5	0.44	0.66
Asphalt Base	4.0	0.34	1.36
Graded Aggregate	7.0	0.14	0.98
			SN = 3.00

The HMA materials are:

1.5 inches Hot Mix Asphalt Superpave 9.5 mm for Surface, PG 64-22, Level 1
4 inches Hot Mix Asphalt Superpave 19 mm for Base, PG 64-22, Level 1

No. 2 Given: 2000 ft. roadway, estimated 8000 vehicles per day. Truck Traffic is 5% of ADT. CBR values = 3.1, 3.5, 3.0, 3.2.

1. Design CBR = $\frac{3.1+3.5+3.0+3.2}{4} = 3.2$
2. Based on the CBR the resilient modulus of the subgrade soils is 4,800 psi (Table 1).
3. The design ESALs are 2,000,000 (Figure B.1).
4. The SN required for a resilient modulus of 4,800 psi is SN = 4.05 (Figure B.2)
5. Pick the appropriate values for layer coefficients from Table 2.

The following alternative could be used:

Pavement Layer	D, in	Layer Coeff.	a_iD_I
Asphalt Surface	2	0.44	0.88
Asphalt Base	6	0.34	2.04
Graded Aggregate	10	0.14	1.14
			SN = 4.06

The HMA materials are:

2 inches Hot Mix Asphalt Superpave 12.5 mm for Surface, PG 64-22, Level 2
6 inches Hot Mix Asphalt Superpave 19.0 mm for Base, PG 64-22, Level 2

CHECKLIST FOR COUNTY REVIEW

See Section 5.0, Submittals, for additional information. Item No. 1 must be completed prior to preliminary plan submittal; the additional items shall be a part of the preliminary plan submittal.

1. Proposed boring location/sample location plan submitted for approval.
2. Certified test results (CBR, classification) of anticipated subgrade soils.
3. Design of subgrade underdrains, if required.
4. Estimated maximum traffic volume.
5. Proposed pavement design, including documentation, method used and Engineer's seal.
6. Documentation that pavement materials, including hot-mix asphalt and graded aggregate subbase meets specifications submitted two weeks prior to use.

REFERENCES

1. *Design Manual Volume I. Roads and Storm Drains*, Carroll County Department of Public Works.

2. *Design of Pavement Structures*, American Association of State Highway and Transportation Officials, 1993.

3. *Standard Specifications for Construction and Materials*, Maryland Department of Transportation, State Highway Administration, 2001.

4. *Design Manual (DRAFT)*, Maryland Department of Transportation, State Highway Administration, Pavement Division, 2001

APPENDIX B

PAVEMENT DESIGN CHARTS

Figure B. 1 - Design ESALs from ADT and Truck Percent

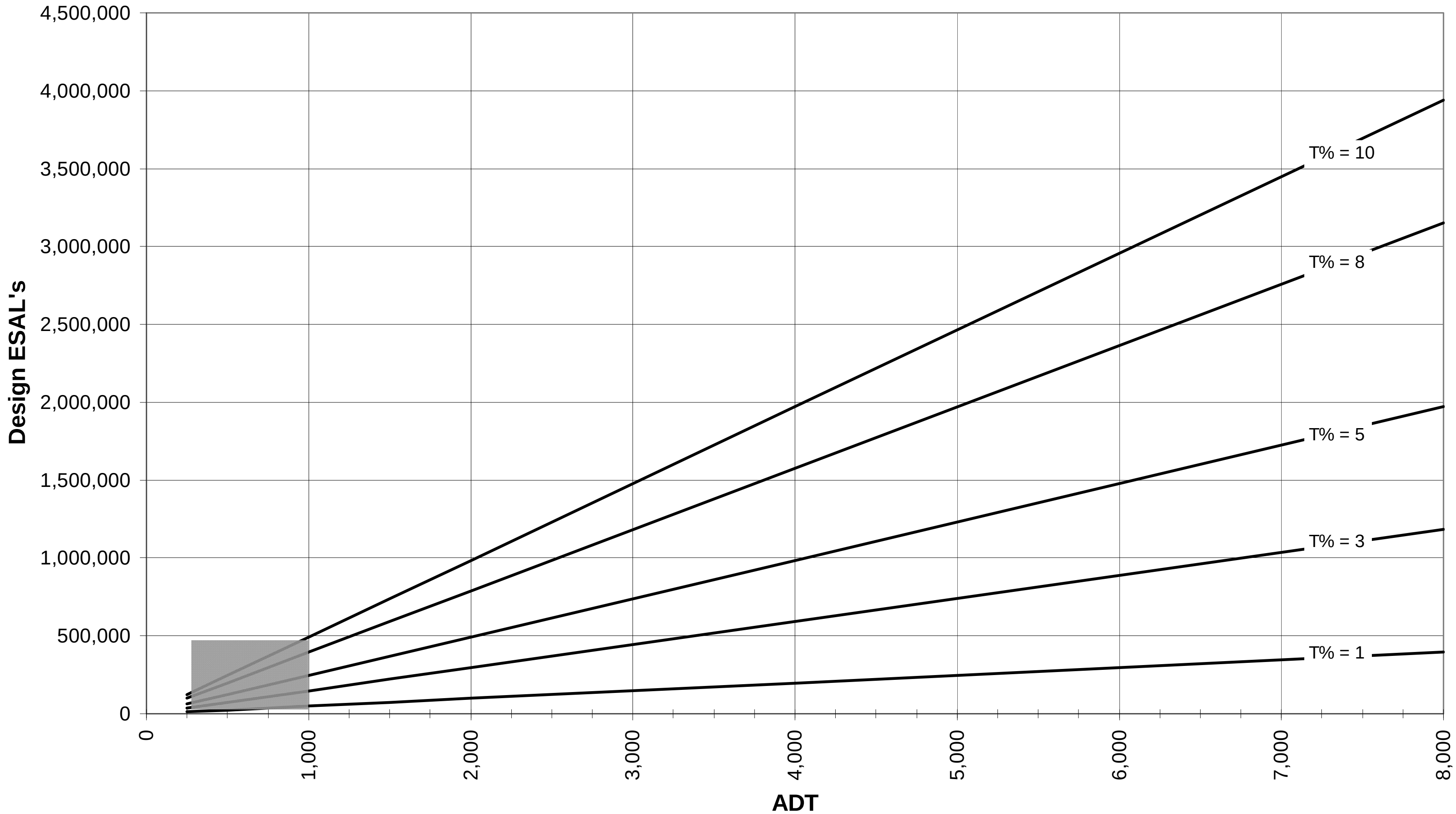

Figure B. 2 - Required Structural Number for Design ESALs and Subgrade Resilient Modulus

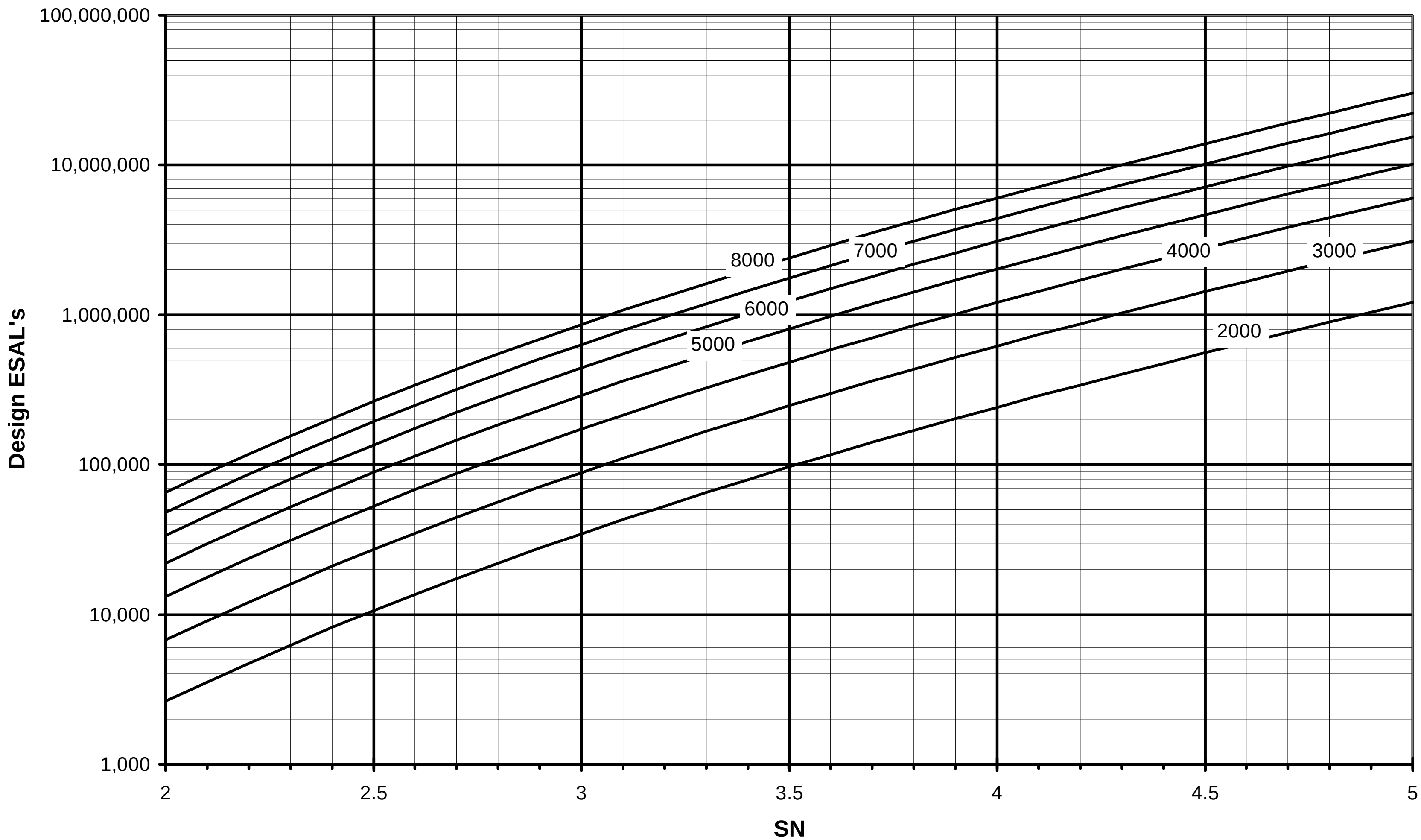

Figure B.2a - Required Structural Number for Design ESALs and Subgrade Resilient Modulus, SN Up to 3.0

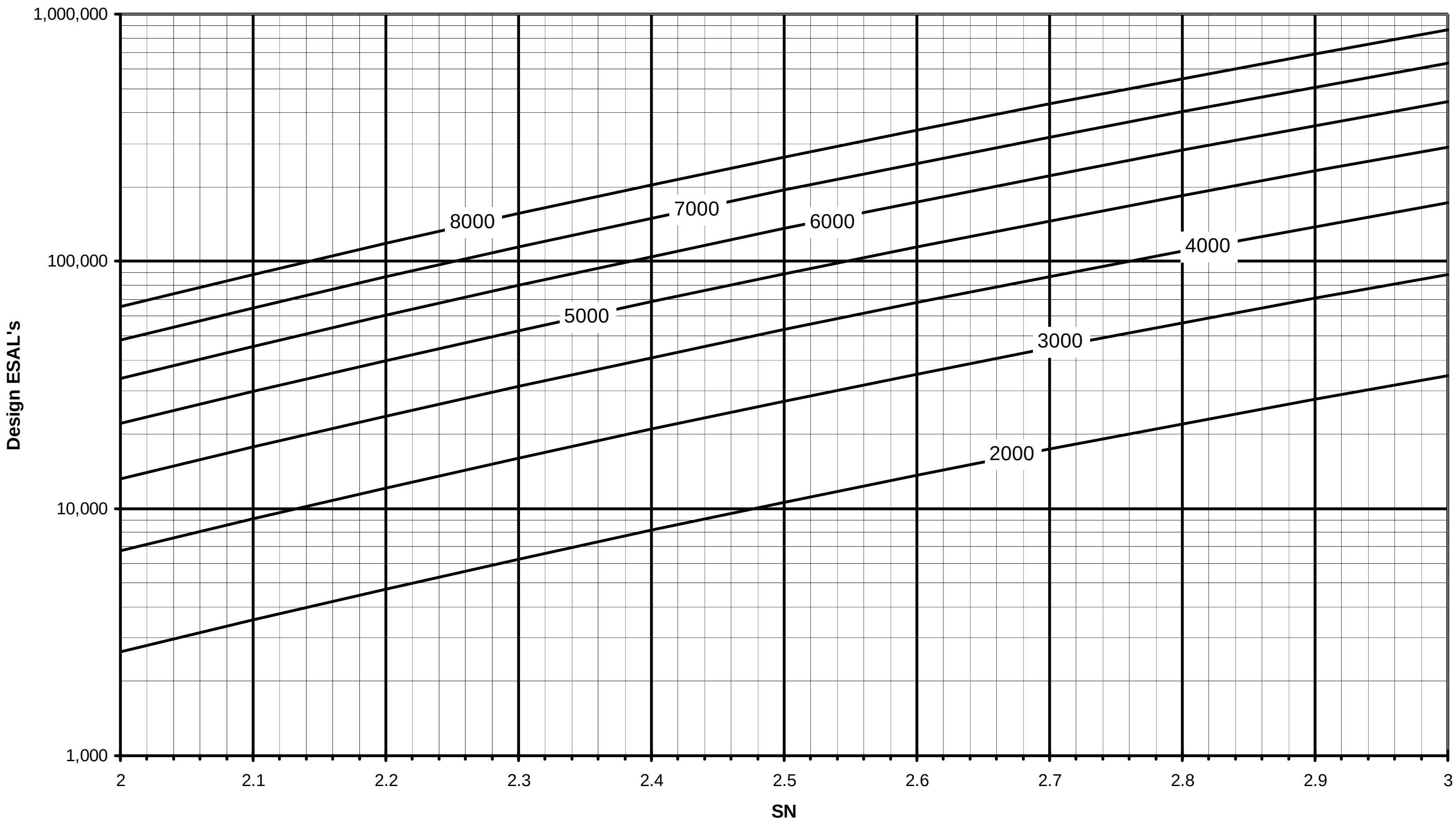

Figure B. 3 - Design ESALs for ADT Up to 1000

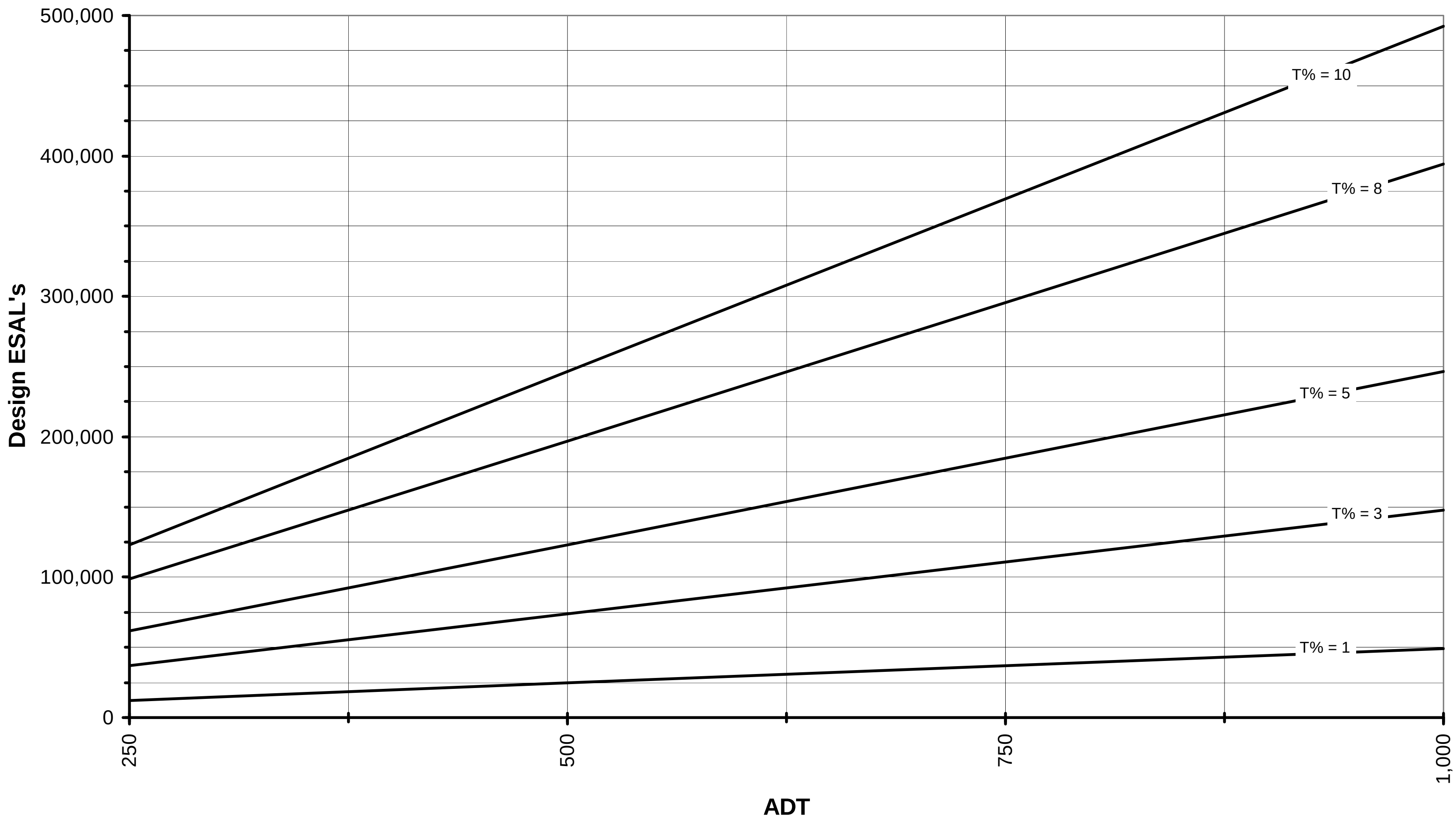

Figure B. 4 - Design ESALs for Commercial/Industrial Roads