Thickness Design of Low-Volume Road Pavement

New York State LTAP Center - Cornell Local Roads Program
David P. Orr, PE, Summer 2021

The NYS LTAP Center - Cornell Local Roads Program developed a new tool to design the thickness of low volume road (LVR) pavements up to 2,000 vehicles per day. This spreadsheet-based tool uses modern mechanistic-empirical methods, but requires only inputs that are typically known by the local pavement engineer or highway official or are obtainable for a reasonable cost. This session will review the critical inputs needed for LVR pavement design and discuss ways for local agencies to design the thickness of their LVRs including the new RoadPE: LHI software.

Resources

Manual: Guidelines for Rural Town and County Roads (pdf),
https://cornell.box.com/clrp-pb-mgrtcr

Highway Standards for Low-Volume Roads in New York State (pdf),
https://cornell.box.com/clrp-pb-hslvrnys

NYSDOT Pavement Models
http://www.clrp.cornell.edu/SeasonalProject/NYSDOTSeasonalHome.htm

Low-Volume Road Thickness: RoadPE: LHI Design Tool
https://www.clrp.cornell.edu/researchprojects/RoadPE_LHI.html

NYSDOT Highway Design Manual
https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm

NYSDOT Comprehensive Pavement Design Manual
https://www.dot.ny.gov/divisions/engineering/design/dqab/cpdm

AASHTO –
American Association of State Highway and Transportation Officials
https://www.transportation.org/

- *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, 2nd Edition*
- *AASHTO Guide for Design of Pavement Structures, 4th Edition with 1998 Supplement*
- *A Policy on Geometric Design of Highways and Streets, 7th Edition*
- *Guidelines for Geometric Design of Low-Volume Roads, 2nd Edition*

RoadPE: LHI - Low-volume Highway Inputs for Pavement Design

Location:	
Route:	
Designer:	
Date:	

Input all known data.

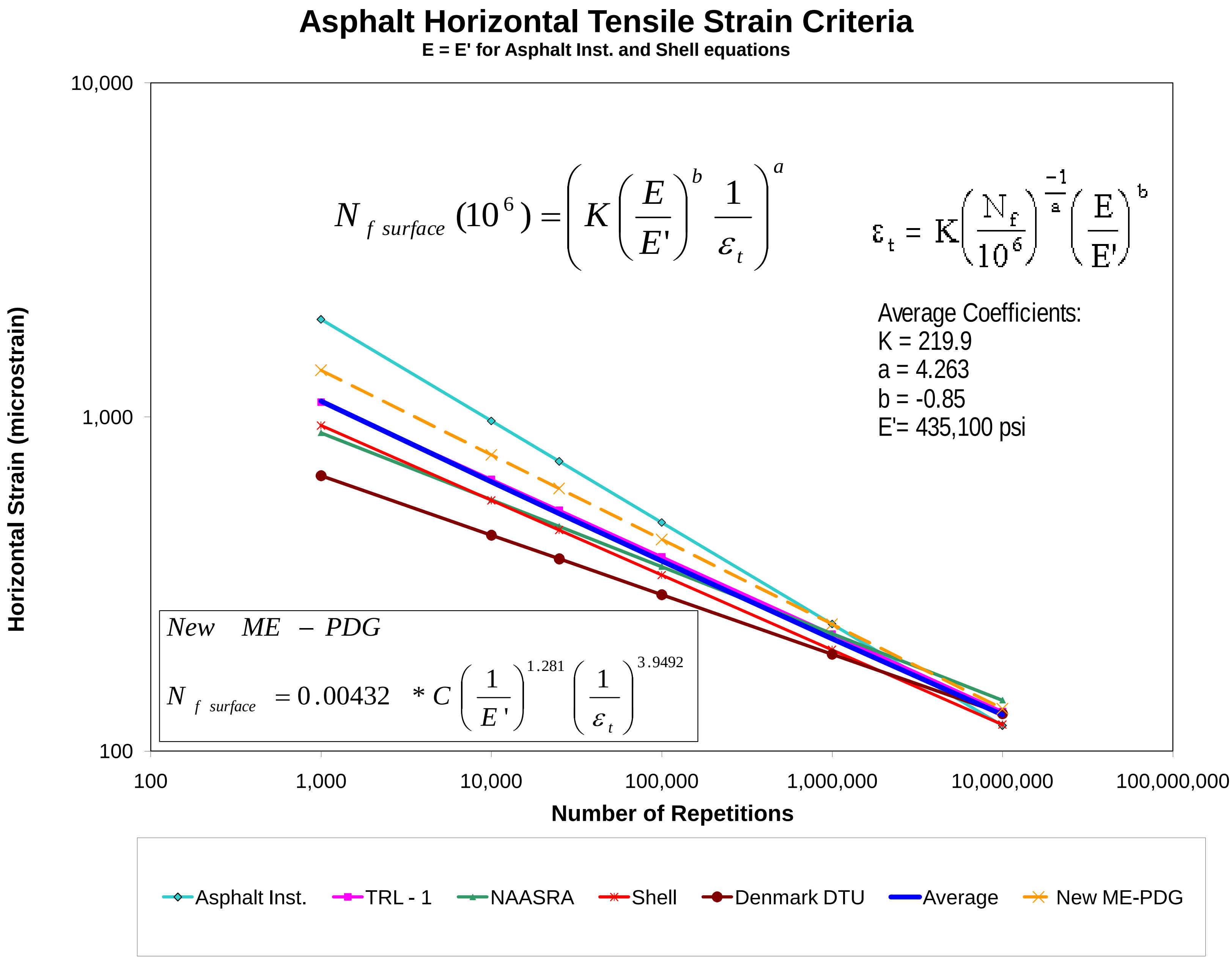
Blue cells must be filled out.
Green cells are drop down list to be chosen by the user.
Yellow cells are optional inputs.
Purple cells are defaults that may be changed by the user.
Orange cells are calculated.

Existing Pavement			
Layer	Layer type	Thickness	
#		in	
1			Cold Mix Asphalt, Gravel surface, Hot Mix Asphalt
2			Crushed gravel/stone (clean), Dirty unbound base (wet), Stabilized, Uncrushed gravel (clean)
3		∞	Clayey subgrade , Gravelly subgrade, Sandy subgrade, Silty subgrade
Drainage Quality			Good, Fair, Poor
Age of current pavement (last major work)			years

Site Inputs				
Seasonal Inputs	Winter	Thaw	Spring	Summer
Length of Season (days)				
Avg. Air Temperature (°F)				

Traffic			
	Deisgn Life		year
	Current vehciles / day		vehicles per day
	Growth Rate	1.0%	NYSDOT Default = 1%
	Traffic Type		Standard LVR, Agricultural, Industrial, Residential, Commercial

Design Inputs				
Work Type	User input (thickness - Inches)		Overlay, Mill & Fill, Rehab, Reconstruct	4
Overlay			Overlay (user may input an override value) [also used with other work types]	
MillFill			Mill and fill (user should input what portion of AC remains after milling)	
Rehab	8.0		Rehab (assumes base will be stabilized 8 inches deep and will have stone base quality when done)	
Reconstruct	12.0		Reconstruct (assumes existing road will be removed to the subgrade) – user will be supply gravel thickness. 12 inches is recommended default	
Drainage Quality After			Good, Fair, Poor	

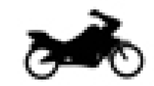
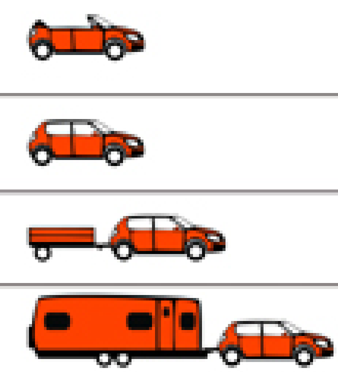
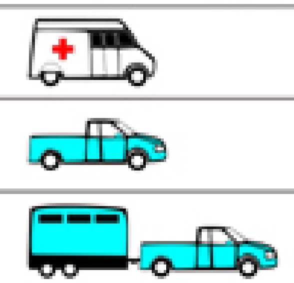
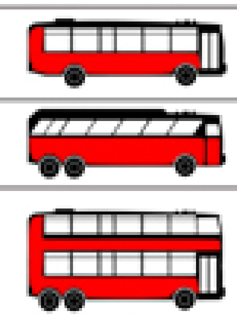
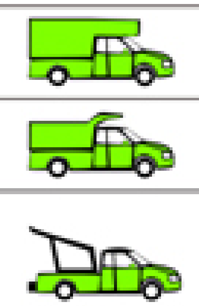
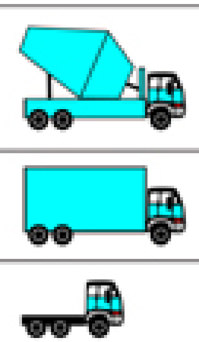
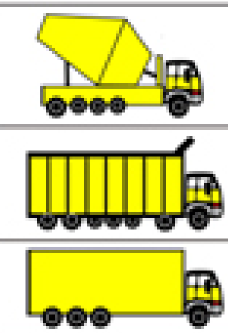
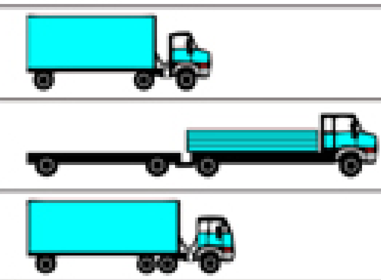
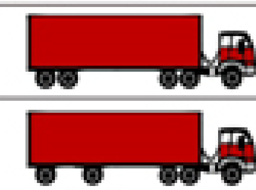
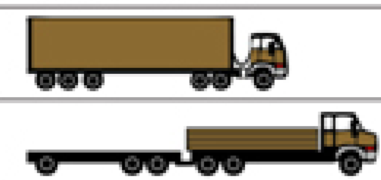
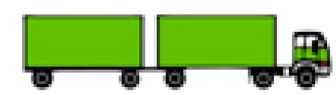
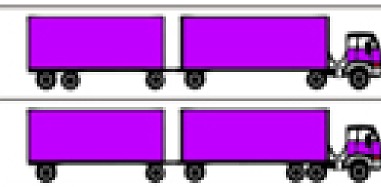
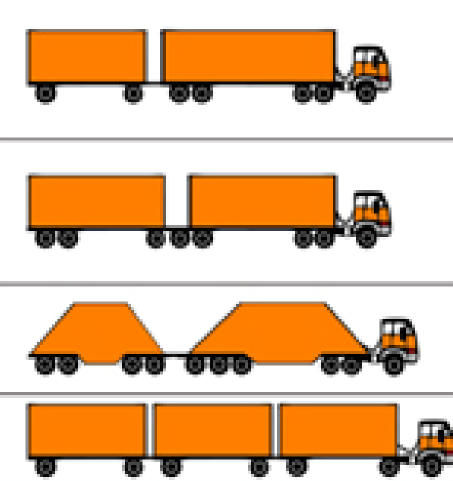


Asphalt Horizontal Tensile Strain Criteria
E = E' for Asphalt Inst. and Shell equations
10,000
1,000
100
Horizontal Strain (microstrain)
$N_{f\ surface}(10^6) = \left(K \left(\frac{E}{E'} \right)^b \frac{1}{\varepsilon_t} \right)^a$
$\varepsilon_t = K \left(\frac{N_f}{10^6} \right)^{\frac{-1}{a}} \left(\frac{E}{E'} \right)^b$
Average Coefficients:
K = 219.9
a = 4.263
b = -0.85
E'= 435,100 psi
New ME – PDG
$N_{f\ surface} = 0.00432 * C \left(\frac{1}{E'} \right)^{1.281} \left(\frac{1}{\varepsilon_t} \right)^{3.9492}$
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
Number of Repetitions
Asphalt Inst.
TRL - 1
NAASRA
Shell
Denmark DTU
Average
New ME-PDG

Typical Values of Young's Elastic Modulus and Poisson's Ratio for Pavement Materials

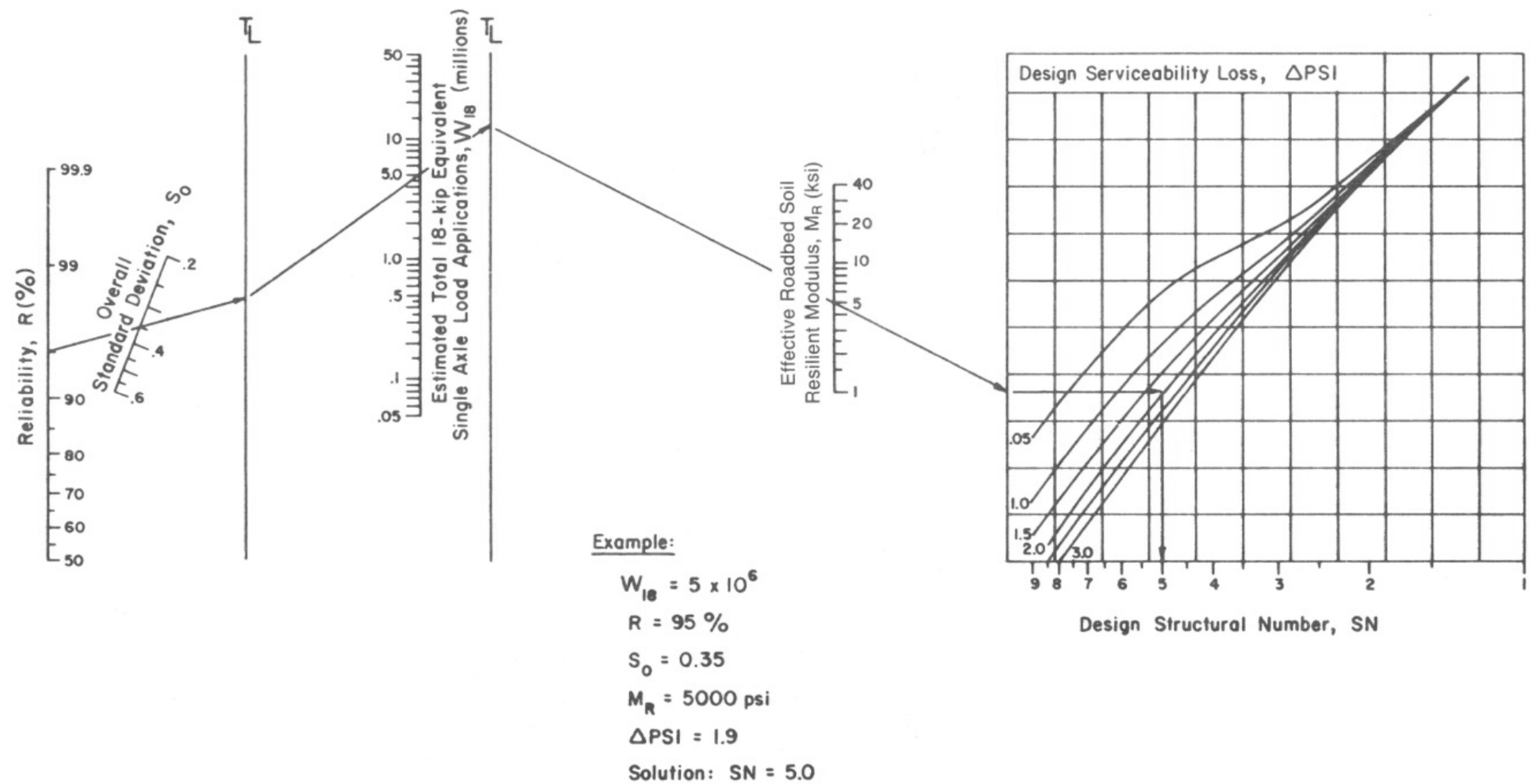
Material		Young's Elastic Modulus (E or M_r), psi	Poisson's Ratio (μ or ν)
Asphalt concrete (uncracked)	32 F 70 F 140 F	2,000,000 – 5,000,000 300,000 – 500,000 20,000 – 50,000	0.25 – 0.30 0.30 – 0.35 0.35 – 0.40
Portland cement concrete (uncracked)		3,000,000 – 5,000,000	0.15
Extensively cracked surfaces		Similar to granular base course materials	Similar to granular base course materials
Crushed stone base (clean, well-drained)		20,000 – 80,000	0.35
Crushed gravel base (clean, well-drained)		20,000 – 80,000	0.35
Uncrushed gravel base Clean, well-drained Clean, poorly-drained		 10,000 – 60,000 3,000 – 15,000	 0.35 0.40
Cement stabilized base Uncracked Badly cracked		 500,000 – 2,000,000 40,000 – 200,000	 0.20 0.30
Cement stabilized subgrade		50,000 – 500,000	0.20
Lime stabilized subgrade		20,000 – 150,000	0.20
Gravelly and/or sandy soil subgrade (drained)		10,000 – 60,000	0.40
Silty soil subgrade (drained)		5,000 – 20,000	0.42
Clayey soil subgrade (drained)		3,000 – 12,000	0.42
Dirty, wet, and/or poorly-drained materials		1,500 – 6,000	0.45 – 0.50
Intact Bedrock Note: Values greater than 500,000 have negligible influence on surface deflections.		250,000 – 1,000,000	0.20

Note: Exceptions to the typical values given above **often** occur. High fines contents and/or high moisture contents tend to reduce Young's modulus and increase Poisson's ratio. Unusually low fines contents and/or low moisture contents have the opposite effect. Poisson's ratio for a completely saturated material will be close to 0.50. Well-cured, asphalt emulsion stabilized gravel, and reclaimed asphalt pavements, will have moduli slightly less than asphalt concrete.

Class 1	Motorcycles	
Class 2	Passenger cars	
Class 3	Four tire, single unit	
Class 4	Buses	
Class 5	Two axle, six tire, single unit	
Class 6	Three axle, single unit	
Class 7	Four or more axle, single unit	
Class 8	Four or less axle, single trailer	
Class 9	5-Axle tractor semitrailer	
Class 10	Six or more axle, single trailer	
Class 11	Five or less axle, multi trailer	
Class 12	Six axle, multi-trailer	
Class 13	Seven or more axle, multi-trailer	

AASHTO '93

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



COMPREHENSIVE PAVEMENT DESIGN MANUAL

Design Division &
Technical Services Division

New York State Department of Transportation

Table 4-1 Conventional Pavement Thickness Guide

Annual Average Daily Traffic AADT[1]	Percent Trucks	Subbase Course (all Pavements)	Portland Cement Concrete Pavement	Hot Mix Asphalt Pavement	
				Base Course	Top & Binder Courses Combined[2]
Over 10,000 Vehicles	10 % or more	300 mm	250 mm	150 mm	90 mm
	less than 10 %			125 mm	
6,000 to 10,000	10 % or more	300 mm	225 mm	125 mm	90 mm
	less than 10 %			100 mm	
4,000 to 5,999	All	300 mm	Not Applicable	75 mm	90 mm
Under 4,000 Vehicles	All	300 mm	Not Applicable	75 mm	80 mm

[1] See Section 4.5.1.1.B for AADT definition.
[2] This is for SUPERPAVE HMA - see Chapter 6 of this manual for individual course thicknesses.

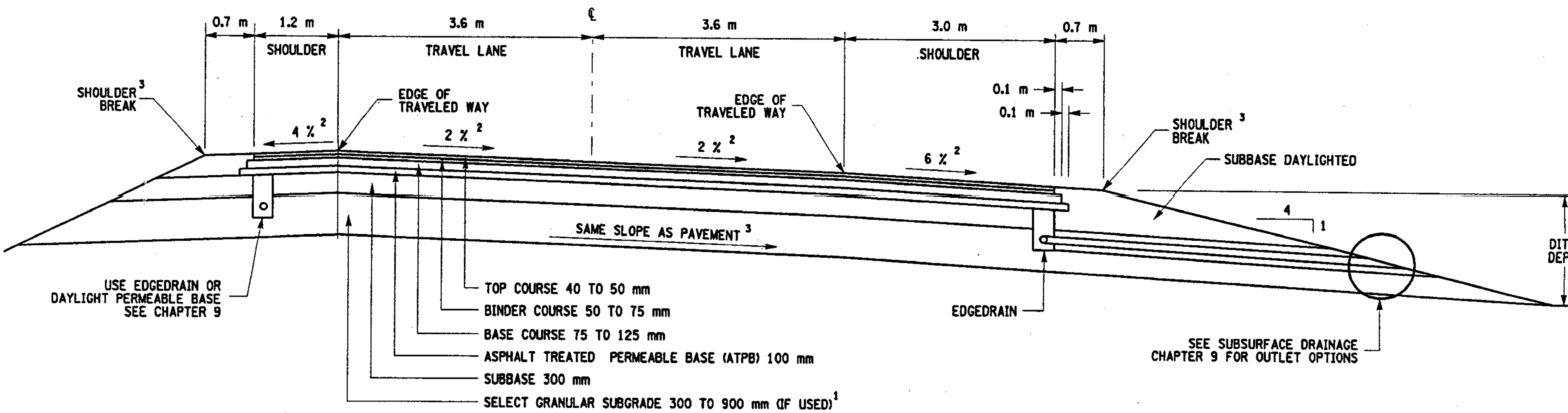
4.5 ESAL-BASED PAVEMENT DESIGN

ESAL-based pavement design is based on the *American Association of State Highway and Transportation Officials (AASHTO) 1993 Guide for the Design of Pavement Structures,* referred to in this manual as the *1993 AASHTO Pavement Design Manual.* Equivalent single axle loads (ESAL) are used for determining pavement thickness and the design relies on using a treated open-graded permeable base layer with continuous edge drains in the pavement structure to provide positive drainage.

The key input variable in the ESAL-based design process is the anticipated amount of heavy truck traffic. The truck traffic is measured and converted to a number of 80 kN ESALs. Section 4.5.1 provides the steps for calculating ESALs using available NYSDOT traffic data.

The *1993 AASHTO Pavement Design Manual* provides a reasonable methodology in designing for adequate structural capacity of the pavement structure. However, it neglects to account for lack of uniform support in the subgrade due to nonuniform, frost-susceptible soils, or to provide adequate support for construction equipment due to unstable subgrade soils. Numerous subgrade improvement methods have been used by NYSDOT in the past to account for these situations.

FIGURE 4-3 TYPICAL HOT MIX ASPHALT PAVEMENT SECTION



THE DIMENSIONS SHOWN ARE TYPICAL ONLY AND THE DETAILS ARE SHOWN TO GIVE THE DESIGNER AN IDEA OF WHAT OVERALL SECTION LOOKS LIKE.

1. SEE CHAPTER 6 FOR MORE INFORMATION OR CONTACT REGIONAL GEOTECHNICAL ENGINEER FOR NECESSITY AND THICKNESS OF SELECT GRANULAR SUBGRADE. DAYLIGHT SELECT GRANULAR SUBGRADE ONTO EMBANKMENT SLOPES OR AT THE EXTENSION OF THE DITCH BACKSLOPE IN CUT SECTIONS.
2. REFER TO THE HIGHWAY DESIGN MANUAL, CHAPTERS 2 AND 3, FOR THE PROPER CROSS SLOPE AND FURTHER DEVELOPMENT OF TYPICAL SECTIONS.
3. REFER TO THE HIGHWAY DESIGN MANUAL, CHAPTER 3, FOR SUBGRADE GRADE CHANGES AND EDGE OF SHOULDER DETAILS.

4.5.3.3 HMA Pavement Thickness

The pavement thickness <u>for all lanes</u> is dependent on the subgrade resilient modulus, M_r, and the amount of traffic in the driving lane (ESALs) and is given in Table 4-5 below. Contact the Regional Geotechnical Engineer to obtain the M_r design value, and also when site conditions would make it difficult to provide the required subbase course and/or select granular subgrade layer thicknesses.

Table 4-5 HMA Thickness Table

M_r = 28 MPa		
80 kN ESALs over Design Life	**Total HMA Thickness**	**Select Granular Subgrade Thickness**
millions	**mm**	**mm**
ESALs ≤ **2**	165	0
2 < ESALs ≤ **4**	175	0
4 < ESALs ≤ **8**	200	0
8 < ESALs ≤ **13**	225	0
13 < ESALs ≤ **23**	250	0
23 < ESALs ≤ **45**	250	150
45 < ESALs ≤ **80**	250	300
80 < ESALs ≤ **140**	250	450
140 < ESALs ≤ **300**	250	600

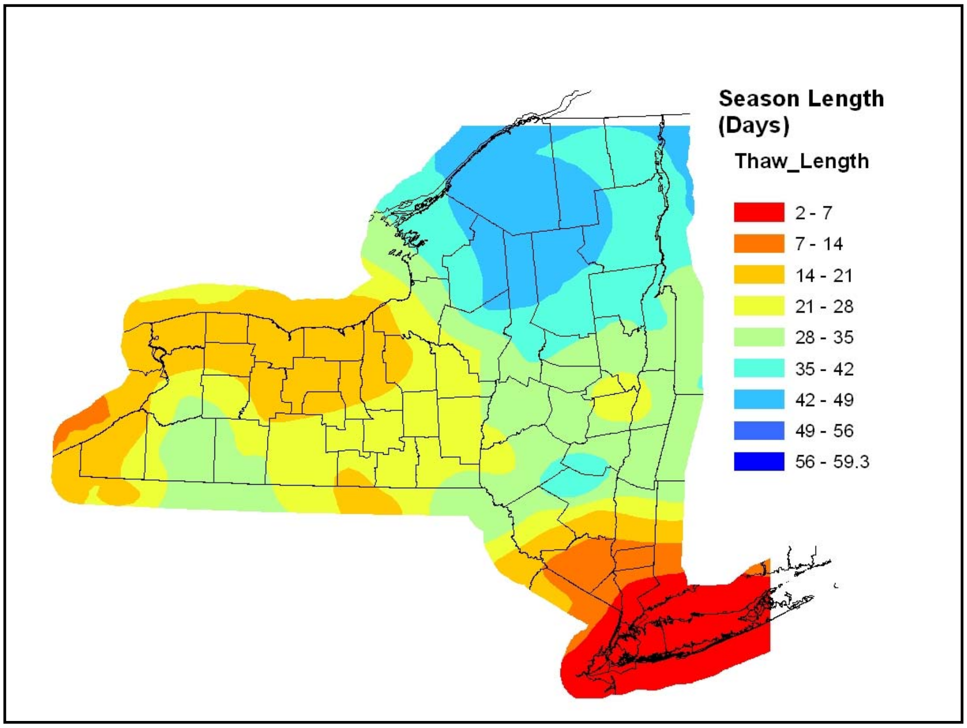
M_r = 34 MPa		
80 kN ESALs over Design Life	**Total HMA Thickness**	**Select Granular Subgrade Thickness**
millions	**mm**	**mm**
ESALs ≤ **4**	165	0
4 < ESALs ≤ **7**	175	0
7 < ESALs ≤ **13**	200	0
13 < ESALs ≤ **23**	225	0
23 < ESALs ≤ **40**	250	0
40 < ESALs ≤ **70**	250	150
70 < ESALs ≤ **130**	250	300
130 < ESALs ≤ **235**	250	450
235 < ESALs ≤ **300**	250	600

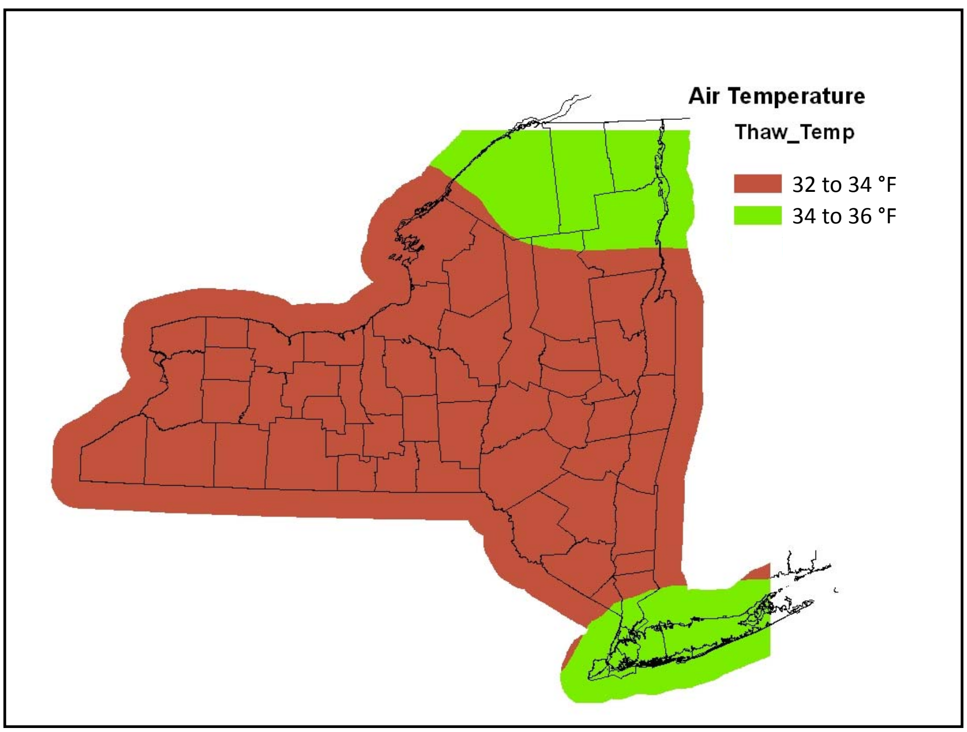
M_r = 41 MPa		
80 kN ESALs over Design Life	**Total HMA Thickness**	**Select Granular Subgrade Thickness**
millions	**mm**	**mm**
ESALs ≤ **6**	165	0
6 < ESALs ≤ **11**	175	0
11 < ESALs ≤ **20**	200	0
20 < ESALs ≤ **35**	225	0
35 < ESALs ≤ **60**	250	0
60 < ESALs ≤ **110**	250	150
110 < ESALs ≤ **200**	250	300
200 < ESALs ≤ **300**	250	450

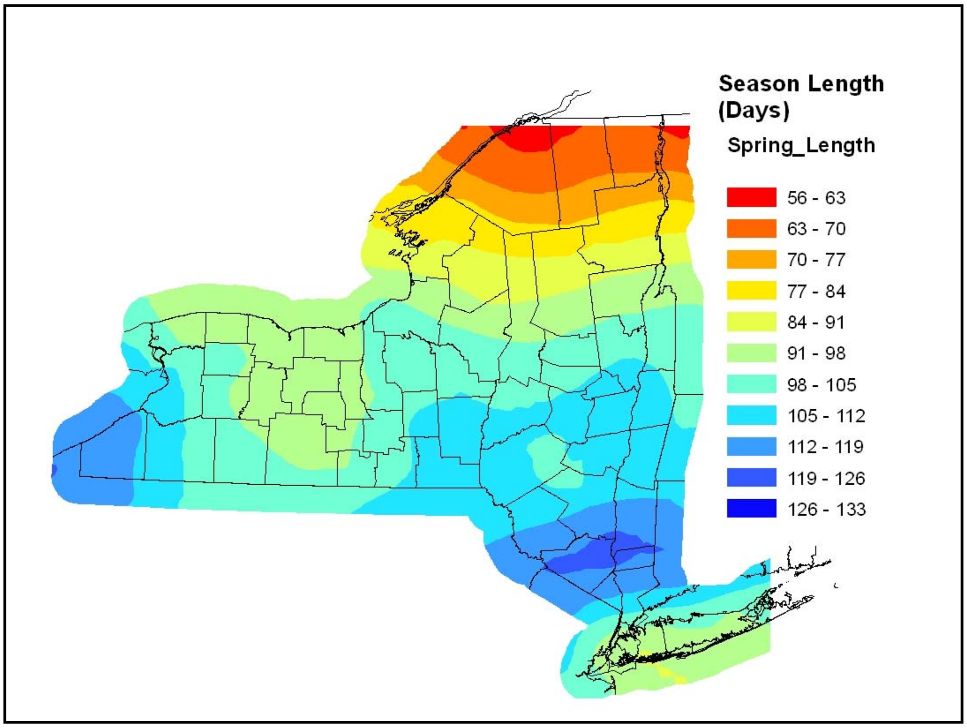
M_r = 48 MPa		
80 kN ESALs over Design Life	**Total HMA Thickness**	**Select Granular Subgrade Thickness**
millions	**mm**	**mm**
ESALs ≤ **8**	165	0
8 < ESALs ≤ **16**	175	0
16 < ESALs ≤ **30**	200	0
30 < ESALs ≤ **50**	225	0
50 < ESALs ≤ **85**	250	0
85 < ESALs ≤ **160**	250	150
160 < ESALs ≤ **300**	250	300

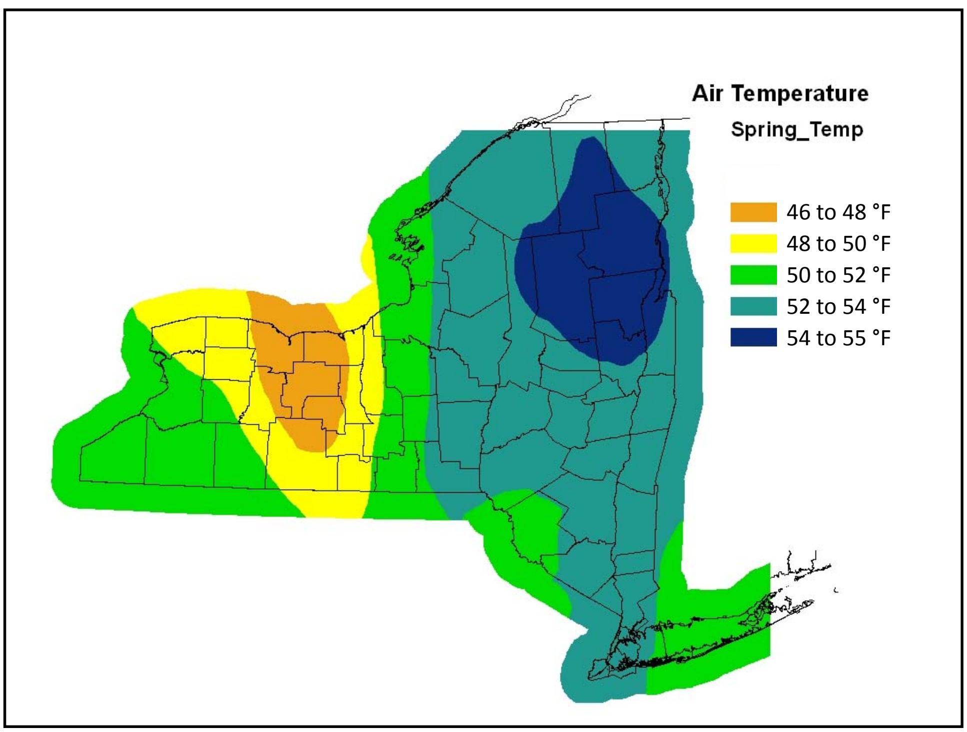
M_r = 55 MPa		
80 kN ESALs over Design Life	**Total HMA Thickness**	**Select Granular Subgrade Thickness**
millions	**mm**	**mm**
ESALs ≤ **12**	165	0
12 < ESALs ≤ **20**	175	0
20 < ESALs ≤ **40**	200	0
40 < ESALs ≤ **65**	225	0
65 < ESALs ≤ **115**	250	0
115 < ESALs ≤ **215**	250	150
215 < ESALs ≤ **300**	250	300

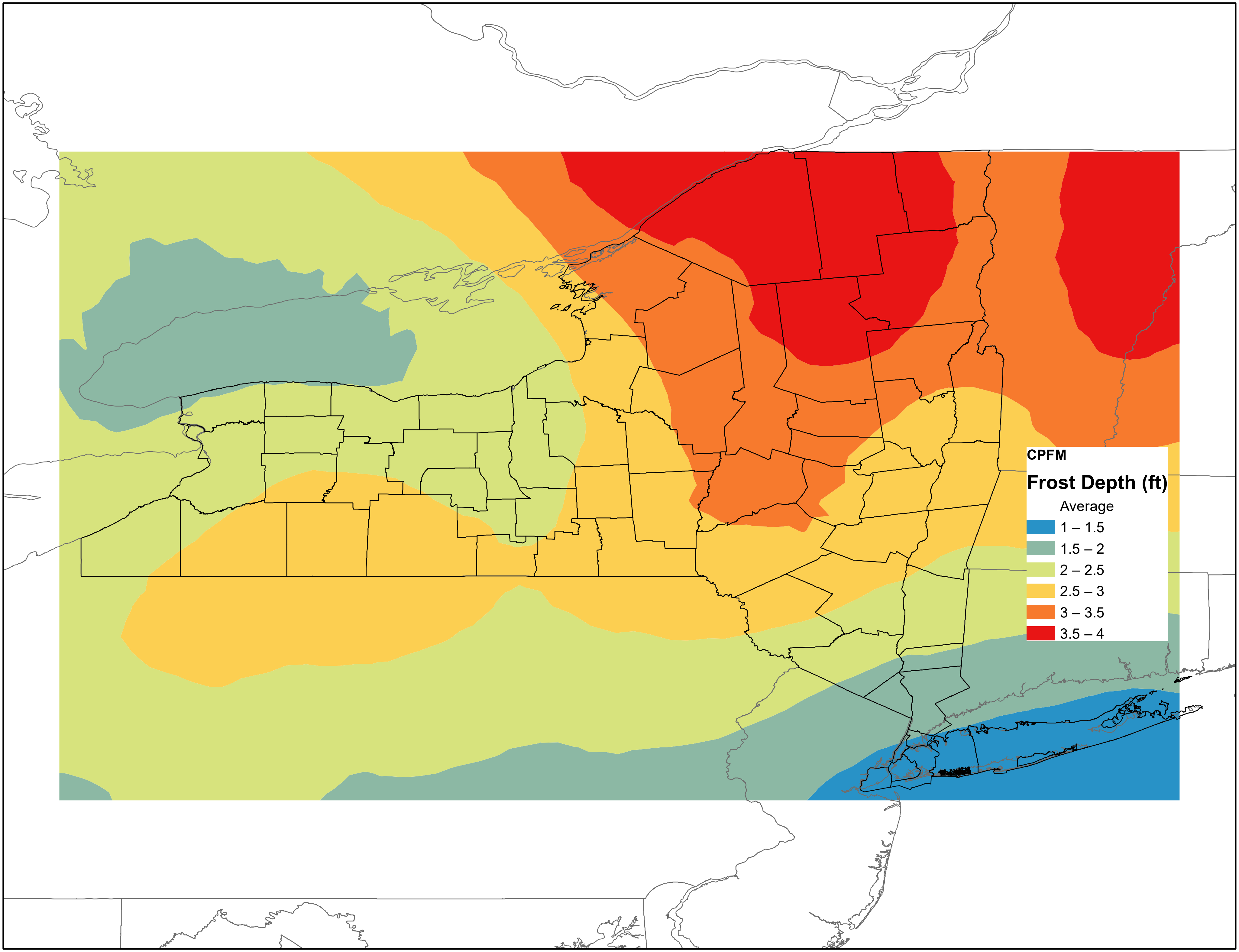
M_r = 62 MPa		
80 kN ESALs over Design Life	**Total HMA Thickness**	**Select Granular Subgrade Thickness**
millions	**mm**	**mm**
ESALs ≤ **15**	165	0
15 < ESALs ≤ **30**	175	0
30 < ESALs ≤ **50**	200	0
50 < ESALs ≤ **90**	225	0
90 < ESALs ≤ **150**	250	0
150 < ESALs ≤ **300**	250	150


Season Length (Days)
Thaw_Length
2 - 7
7 - 14
14 - 21
21 - 28
28 - 35
35 - 42
42 - 49
49 - 56
56 - 59.3


Air Temperature
Thaw_Temp
32 to 34 °F
34 to 36 °F


Season Length
(Days)
Spring_Length
56 - 63
63 - 70
70 - 77
77 - 84
84 - 91
91 - 98
98 - 105
105 - 112
112 - 119
119 - 126
126 - 133


Air Temperature
Spring_Temp
46 to 48 °F
48 to 50 °F
50 to 52 °F
52 to 54 °F
54 to 55 °F


CPFM
Frost Depth (ft)
Average
1 – 1.5
1.5 – 2
2 – 2.5
2.5 – 3
3 – 3.5
3.5 – 4