Pavement Thickness Design Parameter Impacts

2012 Municipal Streets Seminar

November 14, 2012

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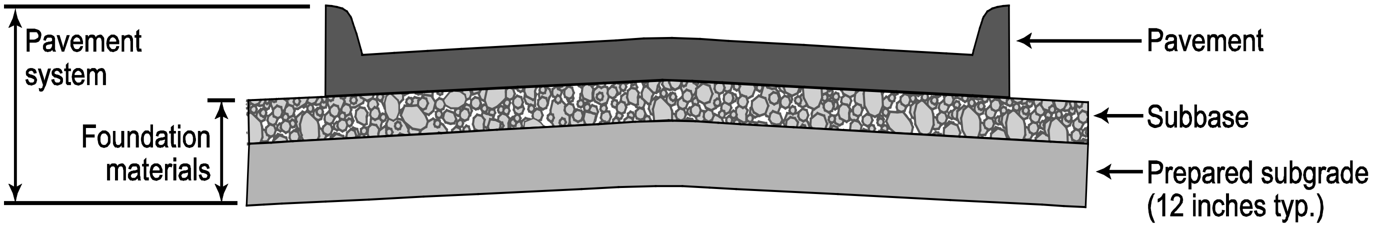
Pavement Thickness Design

- How do cities decide how thick to build their pavements?
  - A data-based analysis
  - Use same thickness streets based on what we have always done
  - Use standard thicknesses based on your city's policies
  - Discuss it with a contractor and do what you can afford

Pavement Thickness Design

- Correct answer – A data-based analysis!
- Doesn't have to be difficult and time consuming
- Several methods available, but design information generally the same
- Terminology:



Pavement Thickness Design

- Good design uses these parameters:
  - Soil characteristics (subgrade)
  - Soil compaction (CBR or DCP)
  - Use of subbase
  - Traffic volumes including % trucks
  - Design Life – 20 to 50 years
  - Expected traffic growth per year over design life
  - Type of pavement – HMA or PCC

Pavement Thickness Design

- Serviceability index
  - Rating system from 5 (perfect) to 0 (impassable)
  - New PCC = 4.5; New HMA = 4.2
  - Terminal Serviceability, P_t

P_t	Classifications
2.00	Secondary Roads and Local Residential Streets
2.25	Minor Collectors, Industrial, and Commercial Streets
2.50	Major Collectors and Arterials

Pavement Thickness Design

- Design Life
  - Old standard = 20 years
  - Current recommendation = 50 years
    - Streets will perform longer and better
    - Limited funds for major rehab and reconstruction

Pavement Thickness Design

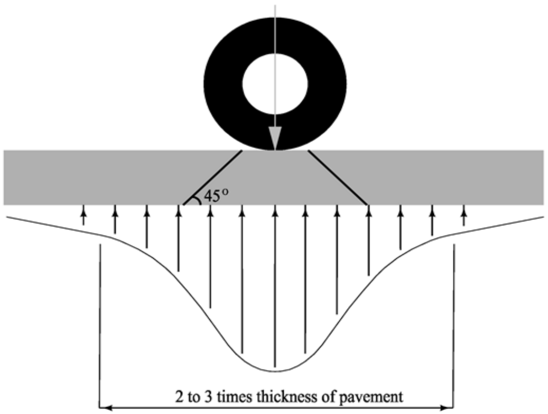
- Design Traffic
  - Average daily traffic volume
  - Percent trucks on the street
    - Usually 2% – 5%
    - Be aware of unusual situations, even if low volume
  - Annual growth rate
    - Usually 2%
  - Length of the analysis period
    - 50 years

Pavement Thickness Design

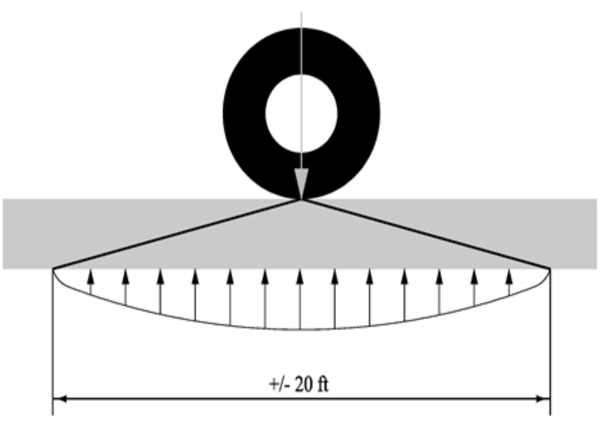
- Truck traffic
  - Cars don’t count – trucks wear out streets
  - Equivalent single axle loads (ESALS)
    - 18,000 pound load used as the standard
    - Different truck types are converted to ESALS
    - Measure of the pavement damage created
  - Different values for PCC and HMA pavements due to different damage created

Pavement Thickness Design

- Pavement Loading Distribution
  - HMA



  - PCC



Pavement Thickness Design

- Soil Resilient Modulus M_R
  - Property of the soil indicating the stiffness or elasticity of the soil under dynamic loading
  - Calculated based on California Bearing Ratio (CBR)

CBR Value	M_R Value
3	4120
5	5840
10	9400

    - Simple strength test comparing a given soil with well-graded crushed stone
  - Used in both HMA and PCC design processes
  - Used directly for HMA design

Pavement Thickness Design

- For PCC, use Modulus of Subgrade Reaction
  - For concrete pavements, uniformity of support is paramount
  - Modulus of Subgrade reaction, $k = M_R / 19.4$
  - Composite Modulus of Subgrade Reaction = (k_c)
    - Used when a subbase is used
    - Represents the strength of the support layer corrected for the additional support from the subbase material

Pavement Thickness Design

- Other important design elements
  - Reliability that the design will exceed the life of the pavement
  - Standard deviation based on AASHTO equations
  - PCC properties
    - Modulus of Elasticity and Modulus of Rupture
  - HMA layer coefficients
    - Used to generate structural numbers
  - Drainage – how long is the subgrade/subbase saturated?
  - Loss of support – PCC only; potential loss of subgrade support due to erosion or differential soil movement

Pavement Thickness Design

- Remember - I said this was easy – right??

Pavement Thickness Design

- Design Methods
  - Asphalt Paving Associations
    - APAI I-Pave (Iowa)
    - PerRoadXpress (Asphalt Institute)
  - American Concrete Paving Association
    - StreetPave
  - AASHTO 1993 Pavement Design Guide
  - SUDAS
    - Section 5F-1

Pavement Thickness Design

- Different design methods give different results based on inputs/default values used in the software/process
- Pavement design is not exact, so ranges of variables are often available
- Within the software, some inputs can be changed and other defaults are not available to users

Pavement Thickness Design

- Design Example:
  - Two lanes
  - Collector classification
  - Average Annual Daily Traffic = 5,000 vpd
  - Percent trucks = 4%
  - Design period = 50 years
  - Annual traffic growth rate = 2%

Pavement Thickness Design

- Asphalt Paving Association
  - I-Pave - Iowa
  - PerRoadXpress - National

I-PAVE

LOW VOLUME ROAD DESIGN GUIDE

DESIGNED BY
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Department of Civil, Construction and Environmental Engineering
Iowa State University

IN COOPERATION WITH

ASPHALT PAVING ASSOCIATION OF IOWA

IOWA STATE UNIVERSITY
Department of Civil Engineering

I-PAVE

LOW VOLUME ROAD DESIGN GUIDE

INPUT | FLEXIBLE | RIGID | FLEX LCCA | RIGID LCCA | SOIL DATA | PRINT | CONTACT

Project Name	Harrington Dr.
Location	Ankeny
County	Polk
Design Period (Y) Years	50

STRUCTURE

	Flexible	Rigid
Stone Base Thickness, in	6	6
Subbase Stabilization Depth, in	12	12
Subbase Soil Type	Unsuitable (Poor)	

Lane Configuration	2
Average Daily Traffic (ADT)	5000
Percent Trucks (T)	4%
Annual Growth Rate (%)	2

ESALs

Terminal Serviceability, pt	2.25
Reliability, R (%)	88

Run Calculations

*AASHTO 1993 (http://training.ce.washington.edu/PGI/)

log(W18) Input	6.20205564901158
log(W18) Predicted	6.20205842324901
Standard Normal Deviate, ZR	-1.17498679174602
Standard Deviation, S0	0.45
ΔPSI	1.95
Effective Subgrade Resilient Modulus, MR (psi)	10000
Structural Number, SN	3.22721000001267
Crushed Stone Elastic Modulus, E2 (psi)	30000
Subgrade Layer Coeff., a3	0
Stabilized Depth, D3	12
Subgrade moisture coeff., m3	1
Granular Subbase Layer Coeff., a2	0.14
Granular Subbase Thickness, D2 (in)	6
Subbase moisture coeff., m2	1
HMA Layer Coefficient, a1	0.44
D1	5.42547727275608
D1 Final	5.5
D1Final2	5.5

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

(these variables will be further explained in Section 3.1.2, *Inputs*)

where:

- W_{18} = predicted number of 80 kN (18,000 lb.) ESALs
- Z_R = standard normal deviate
- S_o = combined standard error of the traffic prediction and performance prediction
- SN = Structural Number (an index that is indicative of the total pavement thickness required)
  - = $a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots$
  - a_i = i^{th} layer coefficient
  - D_i = i^{th} layer thickness (inches)
  - m_i = i^{th} layer drainage coefficient
- DPSI = difference between the initial design serviceability index, p_o, and the design terminal serviceability index, p_t
- M_R = subgrade resilient modulus (in psi)

I-PAVE

LOW VOLUME ROAD DESIGN GUIDE

Terminal Serviceability, pt	2.25
Reliability, R (%)	88

log(W18) Input	6.439
log(W18) Predicted	6.35
Standard Normal Deviate, ZR	-1.175
Standard Deviation, S0	0.35
*Concrete Modulus of Rupture, Sc (psi)	646
Drainage Coeff., Cd	1
Load Transfer Coeff, J	3.2
Concrete Elastic Modulus Ec, psi	4200000
**Modulus of Subgrade Reaction, k (psi/in)	333.33
ΔPSI	2.25
Trial Thickness, D	7.163
Final Thickness, DF	7.5

*Wang, 2008, http://www.intrans.iastate.edu/reports/mepdg_testing.pdf
**Method 1

*Minimum cover requirements limit thickness to 6" for 1 inch dowel bars (http://www.fhwa.dot.gov/pavement/t504030.cfm)

$$\log_{10}(W_{18}) = Z_R \times S_o + 7.35 \times \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1+\frac{1.624\times 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 p_t) \times \log_{10}\left[\frac{(S_c')(C_d)(D^{0.75}-1.132)}{215.63(J)\left(D^{0.75} - \frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right)}\right]$$

(these variables will be further explained in Section 4.1.2, *Inputs*)

where: W_{18} = predicted number of 80 kN (18,000 lb.) ESALs

Z_R = standard normal deviate

I-PAVE
LOW VOLUME ROAD DESIGN GUIDE

INPUT | FLEXIBLE | RIGID | FLEX LCCA | RIGID LCCA | SOIL DATA | PRINT | CONTACT

Relative Quality of Roadbed Soil

Iowa Soil Type	CBR	R-value	Layer Coefficient	DCP (in/blow)	Resilient Modulus Range (Low Moisture to High Moisture), psi		Resilient Modulus, psi	k-value (psi/in), Method 1	k-value (psi/in), Method 2
Select	7	13	0.04	0.56	2,905	11,865	7,385	246	251.00
Suitable	6	11	0.03	0.64	2,765	11,249	7,007	234	232.00
Unsuitable	5	11	0.03	0.53	3,495	9,483	6,489	216	259.00

*Ceylan, 2008, Characterization of Unbound Materials for MEPDG:
MEPDG Work Plan Task 5, Iowa DOT

*For stabilized soils, the following equations are used to characterize the material

$$M_r = 30000\left(\frac{a_i}{0.14}\right) \quad (20)$$

Mr, psi

*This equation is solved for M_r

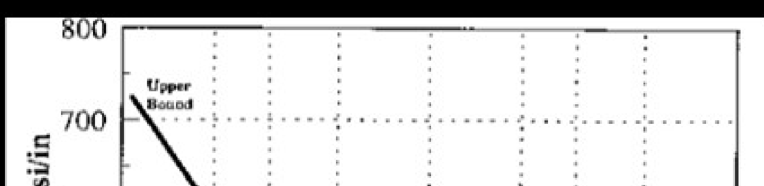
M_r fly ash = 17,500 psi

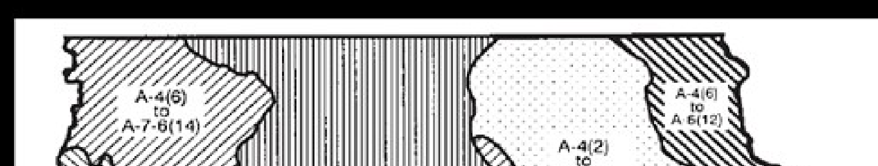
http://www.intrans.iastate.edu/reports/White%20et%20al.%202005_Stab_Vol21.pdf

Effective Modulus of Subgrade Reaction, psi/in

Method 1: $k = M_r/30$

Method 2: Correlation with DCP





I-PAVE

LOW VOLUME ROAD DESIGN GUIDE

INPUT | FLEXIBLE | RIGID | FLEX LCCA | RIGID LCCA | SOIL DATA | PRINT | CONTACT

Project Name	Harrington Dr.
Location	Ankeny
County	Polk
Design Period (Y) Years	50

Lane Configuration	2
Average Daily Traffic (ADT)	5000
Percent Trucks (T)	4
Annual Growth Rate (%)	2

STRUCTURE

	Flexible	Rigid
Stone Base Thickness, in	6	6
Subbase Stabilization Depth, in	12	12
Subbase Soil Type	Unsuitable (Poor)	

ESALs	1,592,413

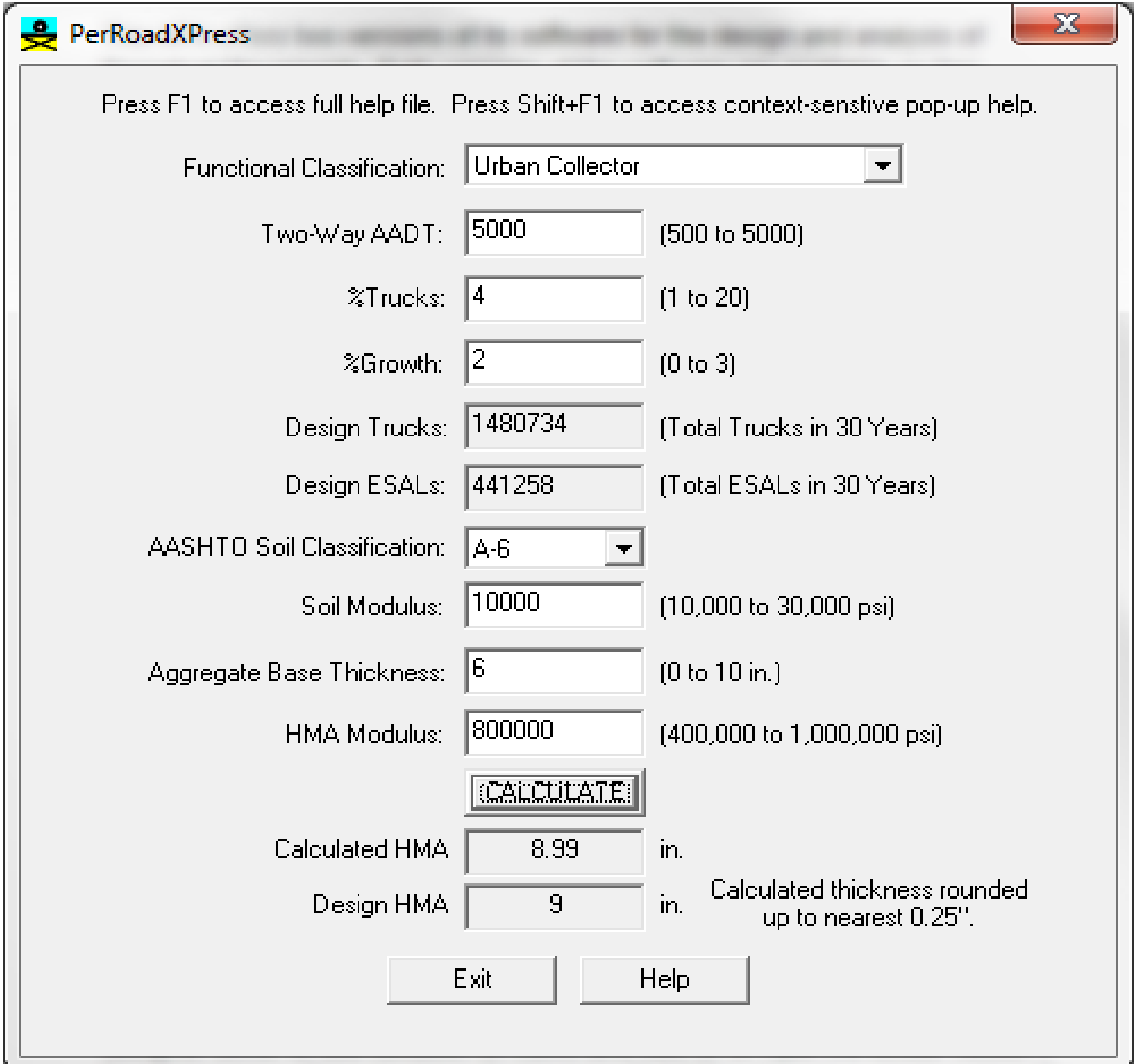
Terminal Serviceability, pt	2.25
Reliability, R (%)	88

Flexible Thickness = 5.5"
Initial Cost = $248,129.65
EUAC Cost = $9,900.19

Run Calculations

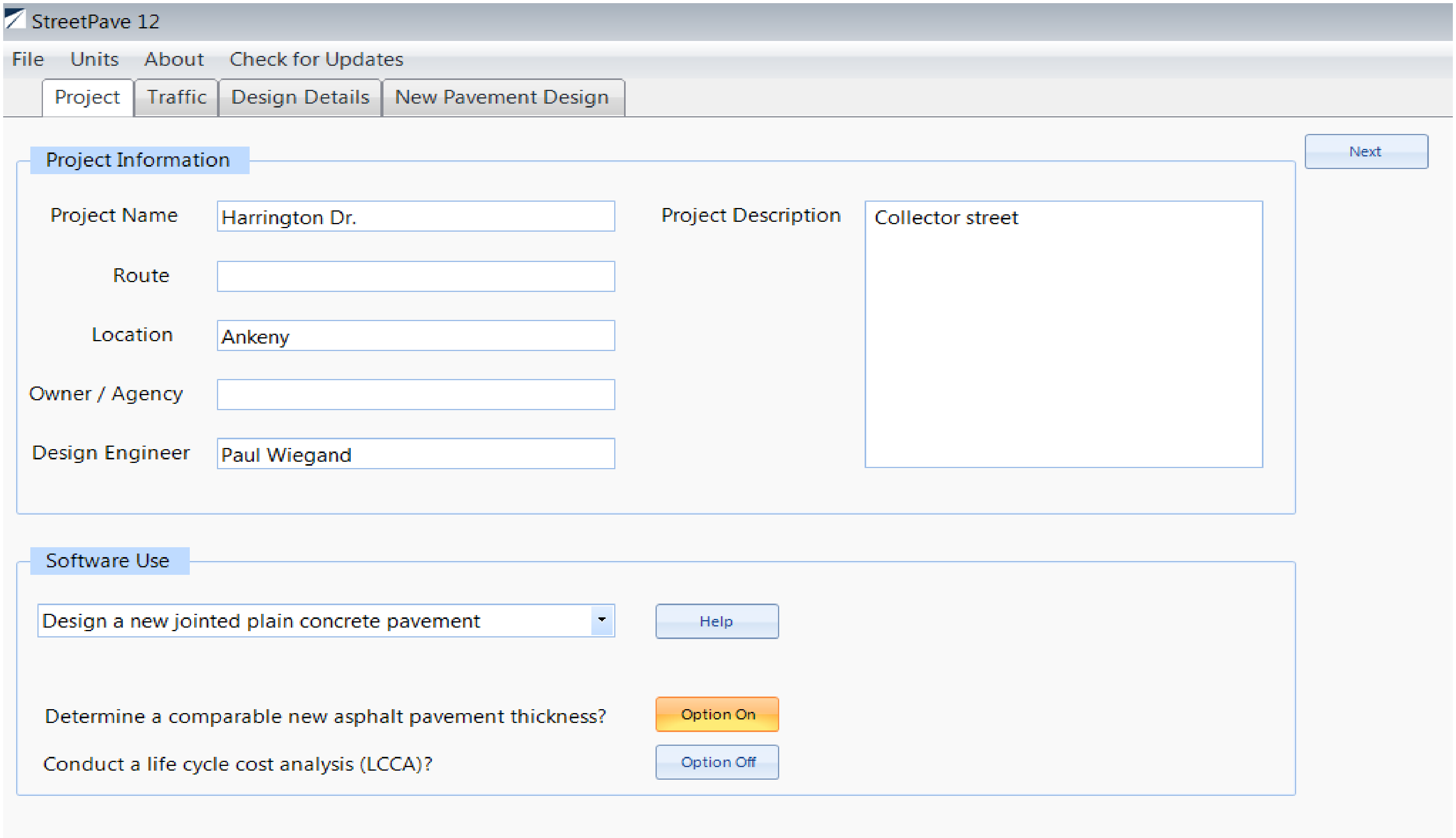
Rigid Thickness = 7.5"
Initial Cost = $352,184.30
EUAC Cost = $10,542.82

SITE BY cylosoft


PerRoadXPress
Press F1 to access full help file. Press Shift+F1 to access context-senstive pop-up help.
Functional Classification:
Urban Collector
Two-Way AADT:
5000
(500 to 5000)
%Trucks:
4
(1 to 20)
%Growth:
2
(0 to 3)
Design Trucks:
1480734
(Total Trucks in 30 Years)
Design ESALs:
441258
(Total ESALs in 30 Years)
AASHTO Soil Classification:
A-6
Soil Modulus:
10000
(10,000 to 30,000 psi)
Aggregate Base Thickness:
6
(0 to 10 in.)
HMA Modulus:
800000
(400,000 to 1,000,000 psi)
CALCULATE
Calculated HMA
8.99
in.
Design HMA
9
in.
Calculated thickness rounded up to nearest 0.25".
Exit
Help

Pavement Thickness Design

- American Concrete Paving Association
  - StreetPave software


StreetPave 12
File
Units
About
Check for Updates
Project
Traffic
Design Details
New Pavement Design
Next
Project Information
Project Name
Harrington Dr.
Route
Location
Ankeny
Owner / Agency
Design Engineer
Paul Wiegand
Project Description
Collector street
Software Use
Design a new jointed plain concrete pavement
Help
Determine a comparable new asphalt pavement thickness?
Option On
Conduct a life cycle cost analysis (LCCA)?
Option Off

StreetPave 12

File Units About Check for Updates

Project | Traffic | Design Details | New Pavement Design

Traffic Category / Load Spectrum

Typical Traffic Spectrums / **ACI 330 Traffic Spectrums**

Help

- ○ Residential / ○ Category A
- ◉ Collector / ○ Category B
- ○ Minor Arterial / ○ Category C
- ○ Major Arterial / ○ Category D

Custom Traffic Spectrum

Truck Traffic over the Pavement Design Life

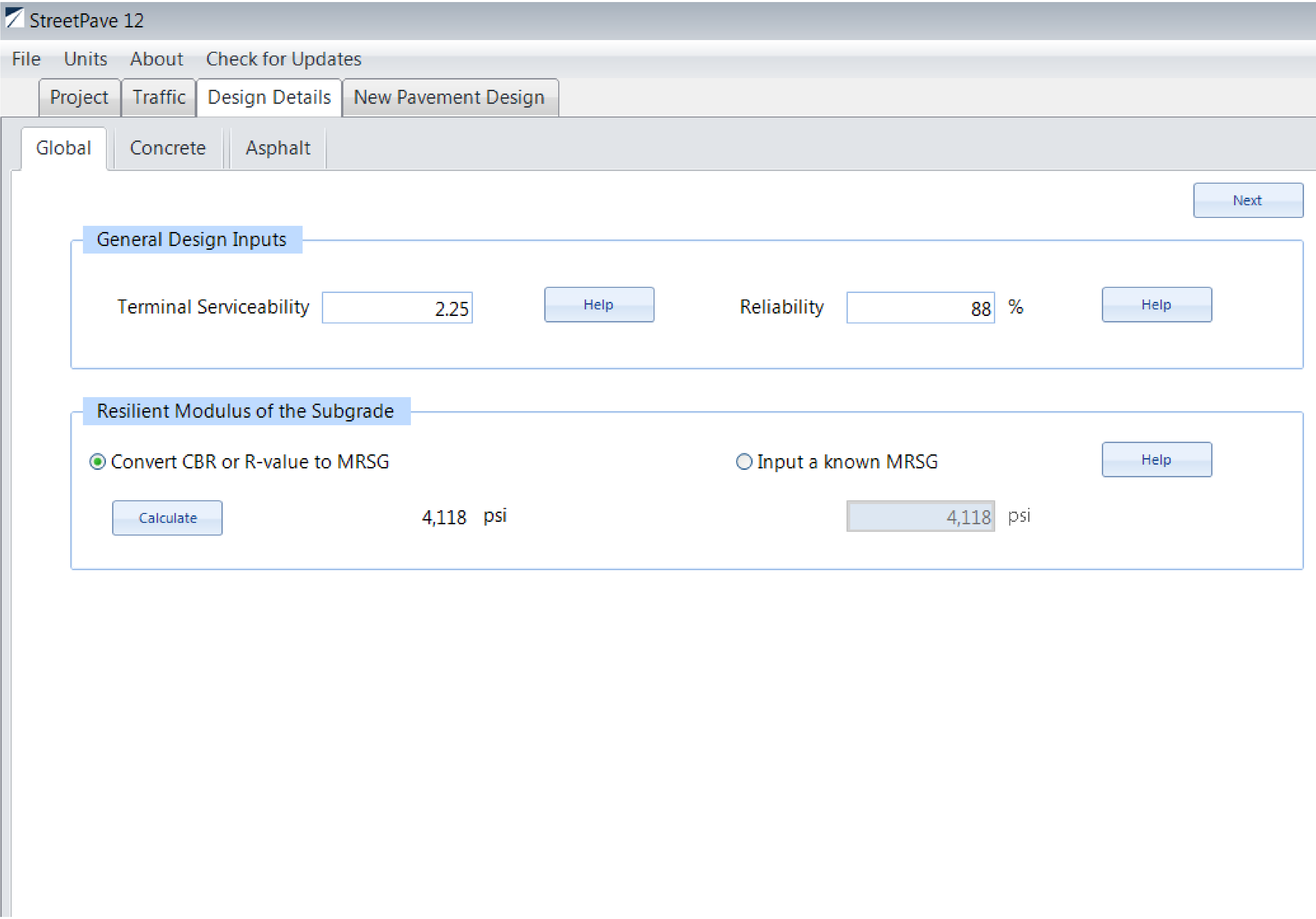
Trucks per Day (two-way, at time of construction)	200		Calculate
Traffic Growth Rate	2	% per year	Help
Design Life	50	years	Help
Directional Distribution	50	%	Help
Design Lane Distribution	100	%	Help

Average Trucks per Day in Design Lane over the Design Life **169**

Total Trucks in Design Lane over the Design Life **8,458**

Next

Traffic Category:	Collector
Axle load, kips	Axles / 1000 trucks
Single Axles	
26	0.07
24	1.6
22	2.6
20	6.63
18	16.61
16	23.88
14	47.76
12	116.76
10	142.7
8	233.6
Tandem Axles	
44	1.16
40	7.76
36	38.79
32	54.76
28	44.43
24	30.74
20	45
16	59.25
12	91.15
8	47.01
Tridem Axles (User Defined Only)	
62	0
56	0
50	0
44	0
38	0
32	0
26	0
20	0
14	0
8	0


StreetPave 12
File
Units
About
Check for Updates
Project
Traffic
Design Details
New Pavement Design
Global
Concrete
Asphalt
Next
General Design Inputs
Terminal Serviceability
2.25
Help
Reliability
88
%
Help
Resilient Modulus of the Subgrade
Convert CBR or R-value to MRSG
Input a known MRSG
Help
Calculate
4,118
psi
4,118
psi

Calculate k-value

Resilient Modulus of the Subgrade: 4,118 psi

Corresponding Subgrade Static k-value: 100 psi/in.

To determine the k-value for a subbase layer system, use the calculator tool below. First input the subbase(s)

Step 1 - From the Top Down, Input Subbase(s) Modulus of Elasticity and

Number of subbase layers between subgrade and concrete pavement: 1 Layer

Top Layer: Unstabilized Subbase (e.g., sand/gravel, crushed stone)

Layer Modulus of Elasticity: 30,000 psi — Help

Allowable Range: 15,000 - 45,000

Layer Thickness: 6 in. — Help

Layer 2: Choose Layer

Layer Modulus of Elasticity: 0 psi

Allowable Range: Choose Layer Type

Layer Thickness: 0 in.

Layer 3: Choose Layer

Layer Modulus of Elasticity: 0 psi

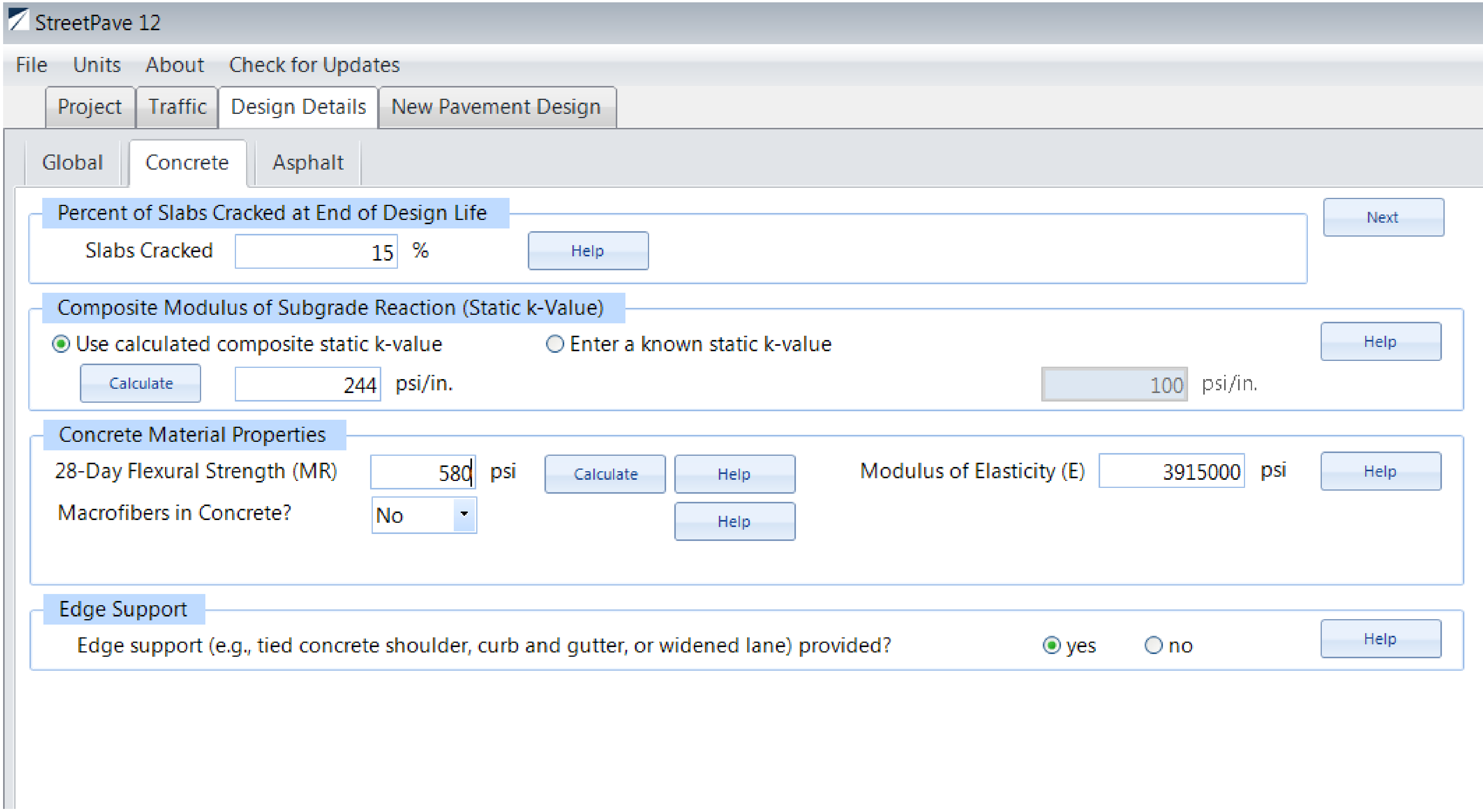
Allowable Range: Choose Layer Type

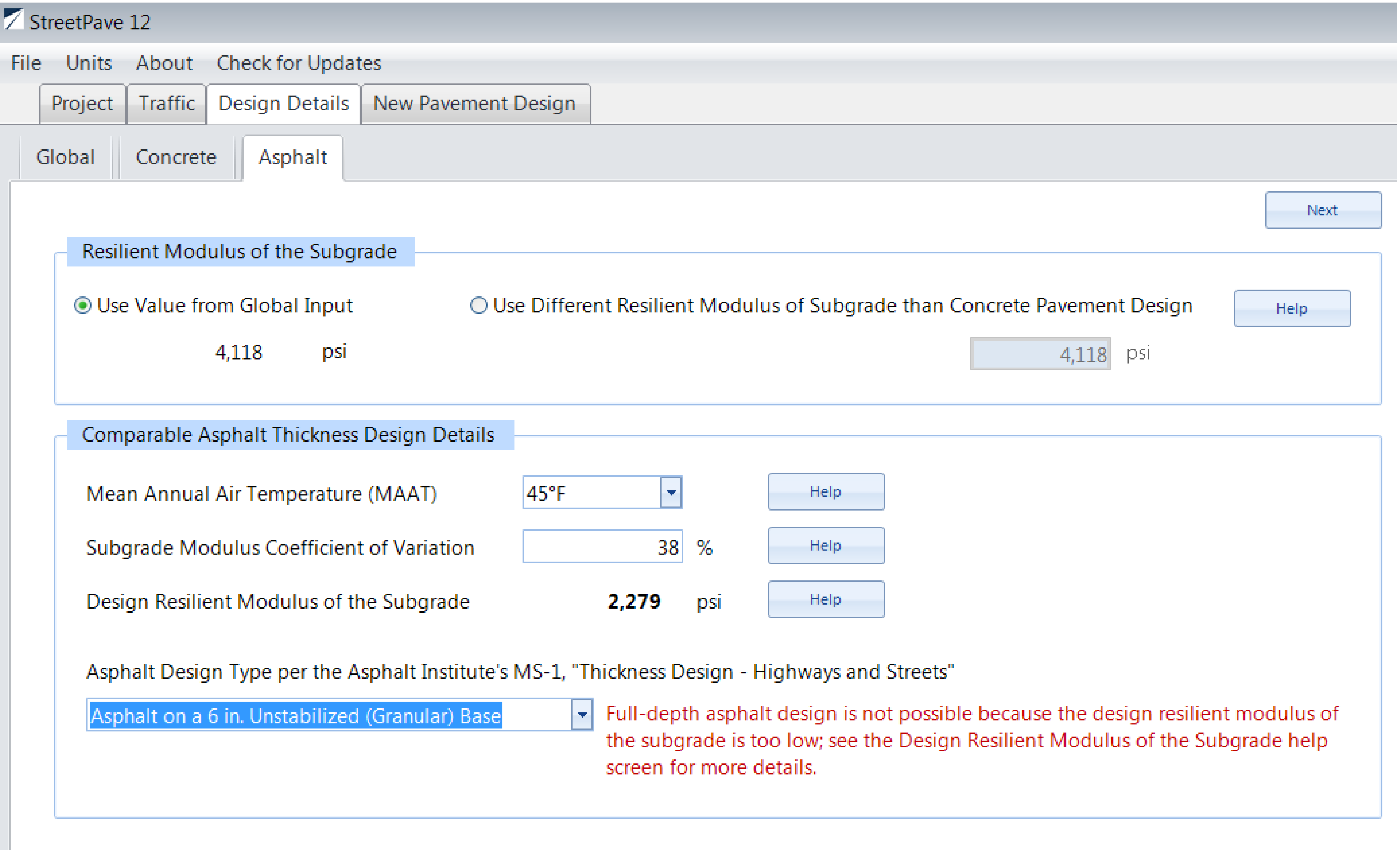
Layer Thickness: 0 in.

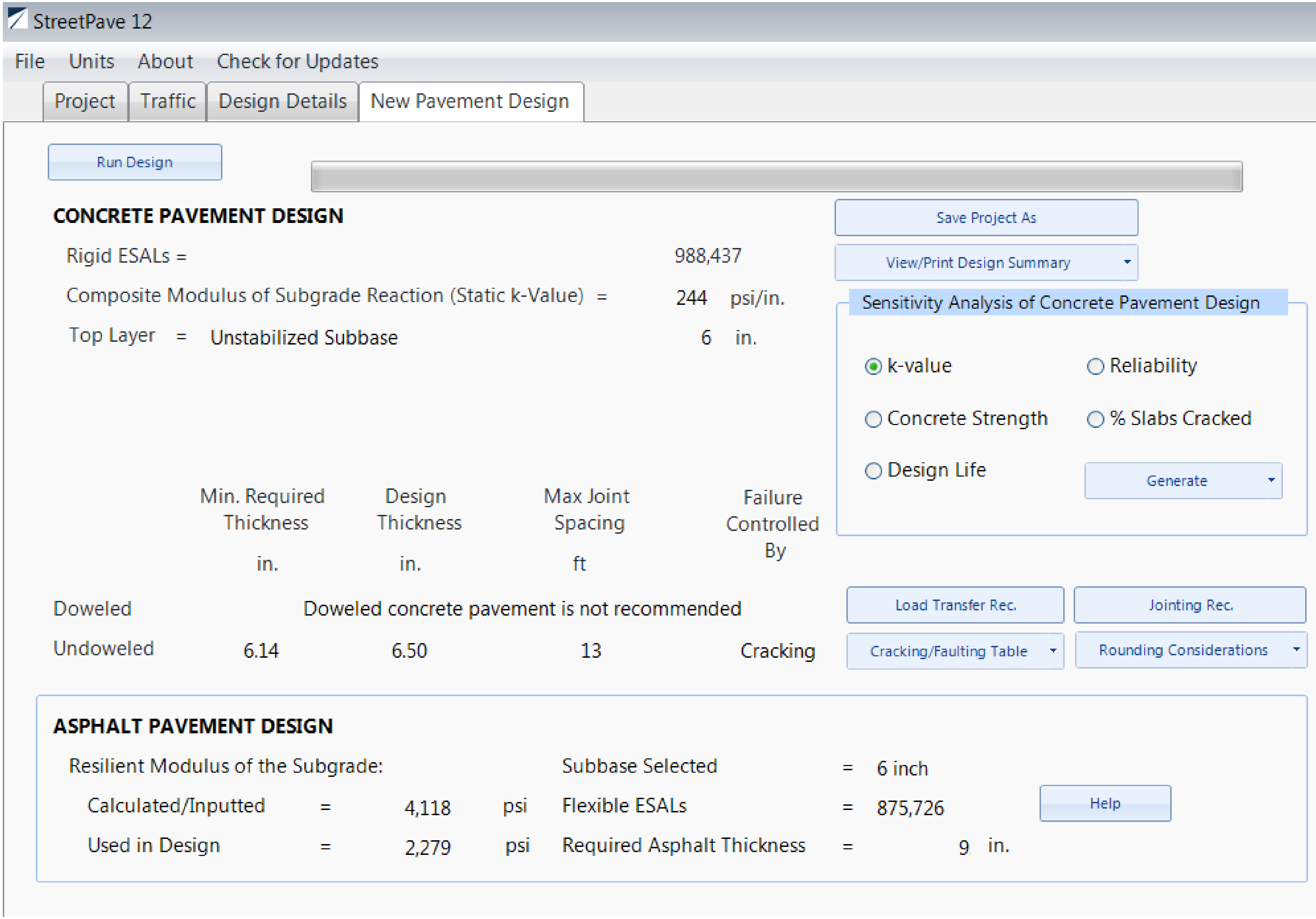
Step 2 - Calculate K

Calculated Composite Static k-Value: 244 psi/in.

Close Window and Save k-Value


StreetPave 12
File
Units
About
Check for Updates
Project
Traffic
Design Details
New Pavement Design
Global
Concrete
Asphalt
Percent of Slabs Cracked at End of Design Life
Slabs Cracked
15
%
Help
Next
Composite Modulus of Subgrade Reaction (Static k-Value)
Use calculated composite static k-value
Enter a known static k-value
Help
Calculate
244
psi/in.
100
psi/in.
Concrete Material Properties
28-Day Flexural Strength (MR)
580
psi
Calculate
Help
Modulus of Elasticity (E)
3915000
psi
Help
Macrofibers in Concrete?
No
Help
Edge Support
Edge support (e.g., tied concrete shoulder, curb and gutter, or widened lane) provided?
yes
no
Help


StreetPave 12
File
Units
About
Check for Updates
Project
Traffic
Design Details
New Pavement Design
Global
Concrete
Asphalt
Next
Resilient Modulus of the Subgrade
Use Value from Global Input
Use Different Resilient Modulus of Subgrade than Concrete Pavement Design
Help
4,118 psi
4,118 psi
Comparable Asphalt Thickness Design Details
Mean Annual Air Temperature (MAAT)
45°F
Help
Subgrade Modulus Coefficient of Variation
38 %
Help
Design Resilient Modulus of the Subgrade
2,279 psi
Help
Asphalt Design Type per the Asphalt Institute's MS-1, "Thickness Design - Highways and Streets"
Asphalt on a 6 in. Unstabilized (Granular) Base
Full-depth asphalt design is not possible because the design resilient modulus of the subgrade is too low; see the Design Resilient Modulus of the Subgrade help screen for more details.

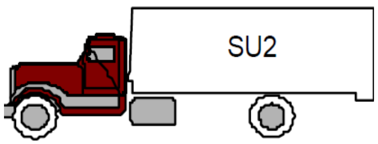
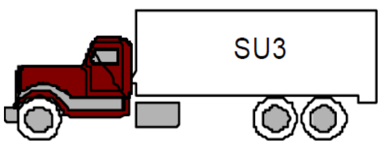
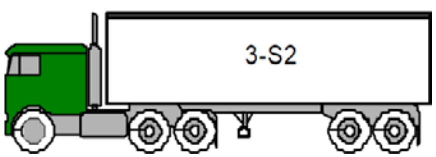


StreetPave 12
File
Units
About
Check for Updates
Project
Traffic
Design Details
New Pavement Design
Run Design
CONCRETE PAVEMENT DESIGN
Rigid ESALs = 988,437
Composite Modulus of Subgrade Reaction (Static k-Value) = 244 psi/in.
Top Layer = Unstabilized Subbase 6 in.
Save Project As
View/Print Design Summary
Sensitivity Analysis of Concrete Pavement Design
k-value
Reliability
Concrete Strength
% Slabs Cracked
Design Life
Generate
Min. Required Thickness in.
Design Thickness in.
Max Joint Spacing ft
Failure Controlled By
Doweled
Doweled concrete pavement is not recommended
Undoweled 6.14 6.50 13 Cracking
Load Transfer Rec.
Jointing Rec.
Cracking/Faulting Table
Rounding Considerations
ASPHALT PAVEMENT DESIGN
Resilient Modulus of the Subgrade:
Calculated/Inputted = 4,118 psi
Used in Design = 2,279 psi
Subbase Selected = 6 inch
Flexible ESALs = 875,726
Required Asphalt Thickness = 9 in.
Help

Pavement Thickness Design

- SUDAS Chapter 5, Section 5F-1
  - Uses 1993 AASHTO Design Guide as the base document
  - Traffic is based on 2010 Iowa DOT traffic inventories
  - Minimum pavement thickness
    - HMA = 6”
    - PCC = 6”

Pavement Thickness Design

Vehicle Type		Percent of Total Trucks	Loading	Percent of Truck Type	Vehicle Weight (lbs)	Axle Type *S - Single* *TA - Tandem*	Axle Load (lbs)	ESAL Factor (per axle) Rigid	ESAL Factor (per axle) Flexible	LEF (by Vehicle) Rigid	LEF (by Vehicle) Flexible
	Single Unit (2 axles) (Class 5/6 Truck)	30%	Empty	30%	14,500	Front - S	7,000	0.019	0.024		
						Rear - S	7,500	0.025	0.032		
			Partial Load (50% Capacity)	50%	20,500	Front - S	8,000	0.033	0.041		
						Rear - S	12,500	0.212	0.242		
			Fully Loaded	20%	26,000	Front - S	9,000	0.053	0.066		
						Rear - S	17,000	0.785	0.799	*0.3033*	*0.3313*
	Dump Trucks - 3 axles (Class 7/8 truck) (doesn't address cheater axles)	10%	Empty	50%	22,000	Front - S	10,000	0.083	0.101		
						Rear - TA	12,000	0.026	0.018		
			Fully Loaded	50%	54,000	Front - S	20,000	1.558	1.52		
						Rear - TA	34,000	1.9	1.099	*1.7835*	*1.369*
	Semis (5 axles)	60%	Empty	20%	26,000	Front - S	12,000	0.178	0.206		
						Rear - TA	7,000	0.003	0.002		
						Trailer - TA	7,000	0.003	0.002		
			Partial Load (50% Capacity)	60%	53,000	Front - S	13,000	0.251	0.282		
						Rear - TA	20,000	0.208	0.138		
						Trailer - TA	20,000	0.208	0.138		
			Fully Loaded	20%	80,000	Front - S	20,000	1.558	1.52		
						Rear - TA	34,000	1.9	1.099		
						Trailer - TA	34,000	1.9	1.099	*1.5086*	*1.1204*
									Composite Load Equivalency Factor (LEF) for "Trucks"	**1.1745**	**0.90853**

Pavement Thickness Design

- Base Year ESALs Rigid Pavement

% Trucks	Two Way, Base Year AADT							
	1,000	***2,000***	***3,000***	***4,000***	***5,000***	***10,000***	***15,000***	***20,000***
1	1,000	3,000	4,000	9,000	11,000	21,000	32,000	43,000
2	3,000	6,000	8,000	17,000	21,000	43,000	64,000	86,000
3	4,000	8,000	13,000	26,000	32,000	64,000	96,000	129,000
4	9,000	17,000	26,000	34,000	43,000	86,000	129,000	171,000
5	11,000	21,000	32,000	43,000	54,000	107,000	161,000	214,000
6	13,000	26,000	39,000	51,000	64,000	129,000	193,000	257,000
7	15,000	30,000	45,000	60,000	75,000	150,000	225,000	300,000
8	17,000	34,000	51,000	69,000	86,000	171,000	257,000	343,000
9	19,000	39,000	58,000	77,000	96,000	193,000	289,000	386,000
10	21,000	43,000	64,000	86,000	107,000	214,000	322,000	429,000
12	26,000	51,000	77,000	103,000	129,000	257,000	386,000	514,000
14	30,000	60,000	90,000	120,000	150,000	300,000	450,000	600,000
16	34,000	69,000	103,000	137,000	171,000	343,000	514,000	686,000
18	39,000	77,000	116,000	154,000	193,000	386,000	579,000	772,000
20	43,000	86,000	129,000	171,000	214,000	429,000	643,000	857,000
22	47,000	94,000	141,000	189,000	236,000	472,000	707,000	943,000
24	51,000	103,000	154,000	206,000	257,000	514,000	772,000	1,029,000
26	56,000	111,000	167,000	223,000	279,000	557,000	836,000	1,115,000
28	60,000	120,000	180,000	240,000	300,000	600,000	900,000	1,200,000
30	64,000	129,000	193,000	257,000	322,000	643,000	965,000	1,286,000

Assume two lane roadway with 50/50 directional split of base year AADT
Values within "box" assume a low volume mix of trucks

Pavement Thickness Design

- Base Year ESALs Flexible Pavement

% Trucks	Two Way, Base Year AADT							
	1,000	***2,000***	***3,000***	***4,000***	***5,000***	***10,000***	***15,000***	***20,000***
1	1,000	2,000	4,000	7,000	8,000	17,000	25,000	33,000
2	2,000	5,000	7,000	13,000	17,000	33,000	50,000	66,000
3	4,000	7,000	11,000	20,000	25,000	50,000	75,000	99,000
4	7,000	13,000	20,000	27,000	33,000	66,000	99,000	133,000
5	8,000	17,000	25,000	33,000	41,000	83,000	124,000	166,000
6	10,000	20,000	30,000	40,000	50,000	99,000	149,000	199,000
7	12,000	23,000	35,000	46,000	58,000	116,000	174,000	232,000
8	13,000	27,000	40,000	53,000	66,000	133,000	199,000	265,000
9	15,000	30,000	45,000	60,000	75,000	149,000	224,000	298,000
10	17,000	33,000	50,000	66,000	83,000	166,000	249,000	332,000
12	20,000	40,000	60,000	80,000	99,000	199,000	298,000	398,000
14	23,000	46,000	70,000	93,000	116,000	232,000	348,000	464,000
16	27,000	53,000	80,000	106,000	133,000	265,000	398,000	531,000
18	30,000	60,000	90,000	119,000	149,000	298,000	448,000	597,000
20	33,000	66,000	99,000	133,000	166,000	332,000	497,000	663,000
22	36,000	73,000	109,000	146,000	182,000	365,000	547,000	730,000
24	40,000	80,000	119,000	159,000	199,000	398,000	597,000	796,000
26	43,000	86,000	129,000	172,000	216,000	431,000	647,000	862,000
28	46,000	93,000	139,000	186,000	232,000	464,000	696,000	929,000
30	50,000	99,000	149,000	199,000	249,000	497,000	746,000	995,000

Assume two lane roadway with 50/50 directional split of base year AADT
Values within "box" assume a low volume mix of trucks

Subbase:	Natural			4" Granular			6" Granular			8" Granular			10" Granular			12" Granular		
CBR Value:	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**
Rigid Pavement Parameters																		
Initial Serviceability Index, P_o	4.5																	
Terminal Serviceability Index, P_t	Local Roads = 2.00 Collector Roads = 2.25 Arterials = 2.50																	
Reliability, R	Local Roads = 80% Collector Roads = 88% Arterial Roads = 95%																	
Overall Standard Deviation, S_o	0.35																	
Loss of Support, LS	1			0														
Soil Resilient Modulus, M_R Per NCHRP Project 128 M_R = 1941.488 X $CBR^{0.6844709}$	4120	5840	9400	4120	5840	9400	4120	5840	9400	4120	5840	9400	4120	5840	9400	4120	5840	9400
Subbase Resilient Modulus, E_{SB} * Assumed	Not Applicable			30,000														
Modulus of Subgrade Reaction, k, and Composite Modulus of Subgrade Reaction, k_c Use AASHTO Chapter 3, Table 3.2 and Figures 3.3 - 3.6 to determine	252	327	469	263	332	455	284	354	477	308	379	504	332	406	535	356	433	566
Adjusted k or k_c for Loss of Support Use AASHTO Part 2, Figure 3.6	85	105	160	263	332	455	284	354	477	308	379	504	332	406	535	356	433	566
Coefficient of Drainage, C_d	1.00			1.10														
Modulus of Rupture, S'_c $S'_c = 2.3 X f_c^{0.667}$ * Assumed 4,000 psi concrete	580																	
Modulus of Elasticity, E_c E_c = 6,750 X S'_c * Assumed 4,000 psi concrete	3,915,000																	
Load Transfer, J	J = 3.1 (Pavement Thickness < 8") J = 2.7 (Pavement Thickness ≥ 8")																	
Flexible Pavement Parameters																		
Initial Serviceability Index, P_o	4.2																	
Terminal Serviceability Index, P_t	Local Roads = 2.00 Collector Roads = 2.25 Arterials = 2.50																	
Reliability, R	Local Roads = 80% Collector Roads = 88% Arterial Roads = 95%																	
Overall Standard Deviation, S_o	0.45																	
Layer Coefficients	Surface/Intermediate Course = 0.44 Base Course = 0.40 Granular Subbase = 0.14																	
Soil Resilient Modulus, M_R Per NCHRP Project 128 M_R = 1941.488 X $CBR^{0.6844709}$	4120	5840	9400	4120	5840	9400	4120	5840	9400	4120	5840	9400	4120	5840	9400	4120	5840	9400
Effective Soil Reslient Modulus, MR Use AASHTO Chapter 2, Figure 2.3 to determine	2460	3480	5580	2460	3480	5580	2460	3480	5580	2460	3480	5580	2460	3480	5580	2460	3480	5580
Coefficient of Drainage, M_i	1.00			1.15														

Pavement Thickness Design

- Rigid Pavement Thickness - Collectors

Subbase	**Natural Subgrade**			**4" Granular**			**6" Granular**		
ESAL/CBR	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**
750,000	7	7	7	6	6	6*	6	6	6*
1,000,000	7.5	7.5	7.5	6.5	6	6	6.5	6	6
1,500,000	8	8	8	7	6.5	6.5	7	6.5	6.5
2,000,000	8	8	8	7.5	7	7	7	7	7
3,000,000	8.5	8	8	8	7.5	7.5	8	7.5	7.5
4,000,000	8.5	8.5	8.5	8	8	8	8	8	8
5,000,000	9	9	8.5	8	8	8	8	8	8
7,500,000	9.5	9.5	9.5	8.5	8.5	8	8.5	8	8
10,000,000	10	10	9.5	9	8.5	8.5	9	8.5	8.5
12,500,000	10.5	10	10	9	9	9	9	9	9
15,000,000	10.5	10.5	10.5	9.5	9.5	9	9.5	9.5	9
17,500,000	11	10.5	10.5	9.5	9.5	9.5	9.5	9.5	9.5
20,000,000	11	11	11	10	10	9.5	10	9.5	9.5

***** The value shown represents a 6 inch minimum; the actual value is less.

Pavement Thickness Design

- Flexible Pavement Thickness - Collectors

Subbase	**Natural Subgrade**			**4" Granular**			**6" Granular**			**8" Granular**			**10" Granular**			**12" Granular**		
ESAL/CBR	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**
750,000	11.5	10.5	9	10	9	7.5	9	8	6.5	8.5	7.5	6*	8	6.5	6*	7	6*	6*
1,000,000	12	10.5	9	10.5	9	7.5	9.5	8.5	7	9	7.5	6	8	7	6*	7.5	6	6*
1,500,000	12.5	11.5	9.5	11	10	8	10.5	9	7.5	9.5	8.5	6.5	9	7.5	6	8	7	6*
2,000,000	13	12	10	11.5	10.5	8.5	11	9.5	8	10	8.5	7	9.5	8	6.5	8.5	7.5	6*
3,000,000	14	12.5	10.5	12.5	11	9	11.5	10	8.5	11	9.5	8	10	8.5	7	9	8	6
4,000,000	---	13	11	13	11.5	9.5	12	10.5	9	11.5	10	8	10.5	9	7.5	10	8.5	6.5
5,000,000	---	13.5	11.5	13.5	12	10	12.5	11	9	11.5	10.5	8.5	11	9.5	8	10	8.5	7
7,500,000	---	14	12	14	12.5	10.5	13.5	12	10	12.5	11	9	11.5	10	8.5	11	9.5	7.5
10,000,000	---	---	12.5	---	13	11	14	12.5	10.5	13	11.5	9.5	12.5	10.5	9	11.5	10	8
12,500,000	---	---	13	---	13.5	11.5	---	12.5	10.5	13.5	12	10	13	11	9	12	10.5	8.5
15,000,000	---	---	13.5	---	14	12	---	13	11	14	12.5	10.5	13	11.5	9.5	12.5	10.5	8.5
17,500,000	---	---	13.5	---	14	12	---	13.5	11.5	---	12.5	10.5	13.5	12	10	12.5	11	9
20,000,000	---	---	14	---	---	12.5	---	13.5	11.5	---	13	11	14	12	10	13	11.5	9

***** The value shown represents a 6 inch minimum; the actual value is less.

Pavement Thickness Design

Two Lane Collector Roadway, PCC
AADT = 5,000
Trucks = 4%
Annual Growth Rate = 2%
Design Period = 50 years

Base Year Design ESALs (from Table 5F-1.07) = 43,000
Growth Factor (from Table 5F-1.11) = 84.6
43,000 ESALs X 84.6 = 3,637,800 ESALs

Subbase	**Natural Subgrade**			**4" Granular**			**6" Granular**		
ESAL/CBR	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**
750,000	7	7	7	6	6	6*	6	6	6*
1,000,000	7.5	7.5	7.5	6.5	6	6	6.5	6	6
1,500,000	8	8	8	7	6.5	6.5	7	6.5	6.5
2,000,000	8	8	8	7.5	7	7	7	7	7
3,000,000	8.5	8	8	8	7.5	7.5	8	7.5	7.5
4,000,000	8.5	8.5	8.5	8	8	8	8	8	8
5,000,000	9	9	8.5	8	8	8	8	8	8

***** The value shown represents a 6 inch minimum; the actual value is less.

Pavement Thickness Design

Two Lane Collector Roadway, HMA
AADT = 5,000
Trucks = 4%
Annual Growth Rate = 2%
Design Period = 50 years

Base Year Design ESALs (from Table 5F-1.08) = 33,000
Growth Factor (from Table 5F-1.11) = 84.6
33,000 ESALs X 84.6 = 2,791,800 ESALs

Subbase	**Natural Subgrade**			**4" Granular**			**6" Granular**			**8" Granular**			**10" Granular**			**12" Granular**		
ESAL/CBR	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**	**3**	**5**	**10**
750,000	11.5	10.5	9	10	9	7.5	9	8	6.5	8.5	7.5	6*	8	6.5	6*	7	6*	6*
1,000,000	12	10.5	9	10.5	9	7.5	9.5	8.5	7	9	7.5	6	8	7	6*	7.5	6	6*
1,500,000	12.5	11.5	9.5	11	10	8	10.5	9	7.5	9.5	8.5	6.5	9	7.5	6	8	7	6*
2,000,000	13	12	10	11.5	10.5	8.5	11	9.5	8	10	8.5	7	9.5	8	6.5	8.5	7.5	6*
3,000,000	14	12.5	10.5	12.5	11	9	11.5	10	8.5	11	9.5	8	10	8.5	7	9	8	6
4,000,000	---	13	11	13	11.5	9.5	12	10.5	9	11.5	10	8	10.5	9	7.5	10	8.5	6.5

* The value shown represents the 6 inch minimum; the actual value is less.

Pavement Thickness Design

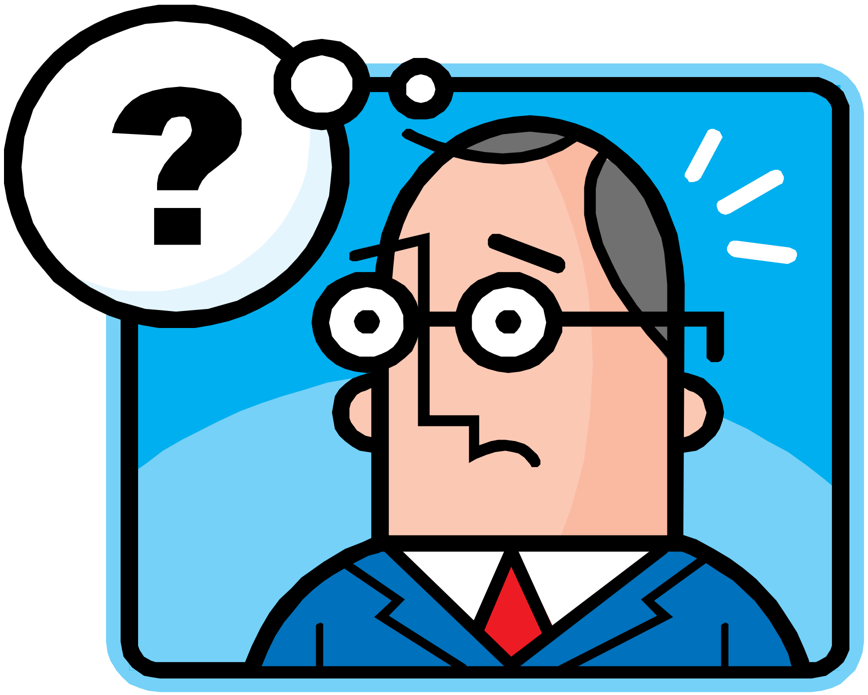
- Summary

Design Model	HMA ESALS	HMA Thickness	PCC ESALS	PCC Thickness
APAI I-Pave	1,591,413	5 ½”	1,591,413	7 ½”
PerRoadXpress	441,258	9”	-----	-----
ACPA StreetPave	875,726	9”	801,589	6 ½”
SUDAS	2,791,800	10”	3,637,800	8”

Pavement Thickness Design

- Inconsistencies in Design Models
  - I-Pave
    - ESAL calculations much different
    - Effective soil M_R = 10,000 psi; AASHTO's value = 3480 psi
  - PerRoadXpress
    - Only 30 year design life
    - M_R = 10,000 psi; AASHTO value = 3480
  - StreetPave
    - ESAL calculations much different
    - For HMA - maximum M_R = 2279 psi; AASHTO's value = 3480 psi

Questions?



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