MODIFICATIONS TO THE APRIL 2000 INTERIM PAVEMENT DESIGN PROCEDURE

November 2007

Page 3 – Terminal Serviceability Index

• *Use 40,000 ADT in lieu of 50,000 ADT in the following sentence.*

A terminal serviceability index (p_t) of 2.75 will be used for roadways where the 20-year traffic projection exceeds *50,000 ADT* with a high heavy truck volume.

Page 4 – Layer Coefficients – Superpave Mix Designs

• *Use the following table in lieu of existing table.*

	English	Metric
Asphalt Concrete Surface Course, Type S9.5X, SF9.5A	0.44	0.017
Asphalt Concrete Surface Course, Type S12.5X	0.44	0.017
Asphalt Concrete Intermediate Course, Type I19.0X	0.44	0.017
Asphalt Concrete Base Course, Type B25.0X	0.30	0.012
Asphalt Concrete Base Course, Type B37.5C	0.30	0.012

Page 6 – Loading Levels

• *Use the following table in lieu of existing table.*

Mix Type	Loading Range (Million ESAL's)	Asphalt Binder Grade
Surface		
SF9.5A	Less than 0.3	PG64-22
S9.5B	Less than 3.0	PG64-22
S9.5C	3 to 30	PG70-22
S12.5C	3 to 30	PG70-22
S12.5D	Over 30	PG76-22
Intermediate		
I19.0B	Less than 3.0	PG64-22
I19.0C	3 to 30	PG64-22
I19.0D	Over 30	PG70-22
Base		
B25.0B	Less than 3.0	PG64-22
B25.0C	3 or Greater	PG64-22
B37.5C	3 or Greater	PG64-22

Page 6 – Unit Weights; Application Rates

• *Use the following table in lieu of existing table.*

Pavement Item	lbs/sy-in.	kg/mm-m^2
SF9.5A	110	2.35
S9.5X	112	2.40
S12.5X	112	2.40
I19.0X	114	2.45
B25.0X	114	2.45
B37.5C	114	2.45
F-1	100	2.15
PADC	90	1.90
ABC	150 Lbs./CF	2400 kg/m^3
CTABC (3.5%Cement)	150 Lbs./CF	2400 kg/m^3

Page 7 – Asphalt Cement Percentages – Superpave Mix Designs

• *Use the following table in lieu of existing table.*

Asphalt Concrete Surface Course, Type SF9.5A	6.5%
Asphalt Concrete Surface Course, Type S9.5X	6.0%
Asphalt Concrete Surface Course, Type S12.5X	5.5% for X=C, 4.8% for X=D
Asphalt Concrete Intermediate Course, Type I19.0X	4.7%
Asphalt Concrete Base Course, Type B25.0X	4.5%
Asphalt Concrete Base Course, Type B37.5C	4.3%

Page 7 – Asphalt Cement Percentages – Other Materials

•*Use the following table in lieu of existing table.*

Permeable asphalt drainage course, Type P-78	3.0%
Permeable asphalt drainage course, Type P-57	2.0%
Sand asphalt base, Type F-1	6.3%
Sand asphalt surface, Type F-1	7.0%

Non-strip Additive................	10 lbs per ton (5.0 kg per Metric Ton) of asphalt cement
Prime Coat...........................	to be used on all pavements with aggregate bases where surface mix is placed directly on ABC at a rate of 0.35 gal. / sy (1.58 L/m^2.)
Asphalt Curing Seal........	for CTABC, Soil cement, and lime treated soil at a rate of 0.15 gal. / sy (0.679 L/m^2).

Page 8 – Pavement Layer Depths

• *Use the following table in lieu of existing table.*

Maximum layer depths: Inches (mm)

SF9.5A = 3.0 (80)
S9.5X = 3.0 (80)
S12.5X = 4.0 (100)
I19.0X = 4.0 (110)
B25.0X = no restrictions
B37.5X = no restrictions

ABC = normally limited to 12 (300), recommended depths are typically 6 (150)*, 8 (200), and 10 (250). *Typically Secondary Roads.
CTABC = 8 (200) for plant mixed; for road mixed 8 (200) with top 7 (175) mixed.

Single lift depths: Inches (mm)

SF9.5A = 1.0(25) to 1.5(40)
S9.5X = 1.5(40) to 2.0(50)
S12.5X = 2.0(50)
I19.0X = 2.5(65) to 4.0 (110)
B25.0X = 3 (75)* to 5.5 (140)
B37.5X = 4.5 (115) to 6.0 (150)
* For B25.0X placed on unstabilized subgrade, the minimum lift thickness is 4.0 (100mm).
ABC = 6(150)** to 10(250)
CTABC = 8 (200)
**8" Preferred minimum on unstabilized subgrade for primary & greater roadways.

Any deviations from these depths will be noted on the pavement design letter.

• *Add B25.0X to the following sentence.*

When less than 4 in. (100mm) of *B25.0X* or HB is used under curb and gutter, Asphalt Curing Seal and Blotting Sand will be recommended for low areas that collect water during construction.

Page 12 – Pavement Drainage – Shoulder Drains

• *Use 40,000 in lieu of 50,000 in the following sentence.*

For projects with average daily traffic of *50,000* and heavy truck percent greater than 15%, shoulder drains are highly recommended.

Page 13 – Pavement Type Selection

• *Use 1986 in lieu of 1993 in the following sentence.*

The process will closely follow the type selection guidelines as presented in Appendix B of the *1993* Guide for the Design of Pavement Structures.

• *Use these tables in lieu of Table A-1and A-2 in the appendix.*

Table A-1 Recommended Bridge Replacement Pavement Design - (Superpave, Full Depth)

	English Units (Inches)				Metric Units (Millimeters)			
Structural Number Range	Surface	Inter.	Base	Structural Number	Surface	Inter.	Base	Structural Number
<2.32	2.5 SF9.5A		4.0 B25.0B	2.30	60 SF9.5A		110 B25.0B	2.34
2.33 - 2.50	2.5 SF9.5A		4.5 B25.0B	2.45	60 SF9.5A		120 B25.0B	2.46
2.51 - 2.62	2.5 SF9.5A		5.0 B25.0B	2.60	60 SF9.5A		130 B25.0B	2.58
2.63 - 2.80	2.5 SF9.5A		5.5 B25.0B	2.75	60 SF9.5A		140 B25.0B	2.70
2.81 - 3.42	2.5 SF9.5A	2.5 I19.0B	4.0 B25.0B	3.40	60 SF9.5A	65 I19.0B	100 B25.0B	3.33
<2.77	3.0 S9.5B		4.5 B25.0B	2.67	80 S9.5B		110 B25.0B	2.68
2.78 - 2.89	3.0 S9.5B		5.0 B25.0B	2.82	80 S9.5B		120 B25.0B	2.80
2.90 - 3.07	3.0 S9.5B		5.5 B25.0B	2.97	80 S9.5B		140 B25.0B	3.04
3.08 - 3.69	3.0 S9.5B	2.5 I19.0B	4.0 B25.0B	3.62	80 S9.5B	65 I19.0B	100 B25.0B	3.67
3.70 - 3.84	3.0 S9.5B	2.5 I19.0B	4.5 B25.0B	3.77	80 S9.5B	65 I19.0B	110 B25.0B	3.79
3.85 - 3.99	3.0 S9.5B	2.5 I19.0B	5.0 B25.0B	3.92	80 S9.5B	65 I19.0B	120 B25.0B	3.91
4.00 - 4.17	3.0 S9.5B	2.5 I19.0B	5.5 B25.0B	4.07	80 S9.5B	65 I19.0B	140 B25.0B	4.15

Table A-2 Recommended Bridge Replacement Pavement Design - (Superpave, ABC)

	English Units (Inches)				Metric Units (Millimeters)			
Structural Number Range	Surface	Inter.	ABC	Structural Number	Surface	Inter.	ABC	Structural Number
<1.95	2.5 SF9.5A *		6	1.94	60 SF9.5A *		150	1.85
1.96 - 2.22	2.5 SF9.5A *		8	2.22	60 SF9.5A *		200	2.12
2.23 - 2.50	2.5 SF9.5A *		10	2.50	60 SF9.5A *		250	2.40
2.51 - 3.05	2.5 SF9.5A	2.5 I19.0B	6	3.04	60 SF9.5A	65 I19.0B	150	2.95
3.06 - 3.33	2.5 SF9.5A	2.5 I19.0B	8	3.32	60 SF9.5A	65 I19.0B	200	3.23
3.34 - 3.42	2.5 SF9.5A	2.5 I19.0B	10	3.60	60 SF9.5A	65 I19.0B	250	3.50
<3.36	3.0 S9.5B	2.5 I19.0B	6	3.26	80 S9.5B	65 I19.0B	150	3.29
3.37 - 3.63	3.0 S9.5B	2.5 I19.0B	8	3.54	80 S9.5B	65 I19.0B	200	3.57
3.64 - 3.92	3.0 S9.5B	2.5 I19.0B	10	3.82	80 S9.5B	65 I19.0B	250	3.84

*** Prime coat required**

INTERIM PAVEMENT DESIGN PROCEDURE

N. C. Department of Transportation

Pavement Management Unit
April 1, 2000

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INTRODUCTION

The pavement design guidelines included herein are to be used for the design of all new and rehabilitated TIP project pavements in North Carolina. This procedure will be updated as necessary to include new developments in design and analysis procedures and will be distributed to Division Engineers and Pavement Review Committee members. This edition includes both English and metric units.

PAVEMENT DESIGN EQUATIONS

The AASHTO design equations as presented in the AASHTO Interim Guide for Design of Pavement Structures, 1972 are to be used for the design of both flexible and rigid pavements. For flexible designs, required inputs will be a regional factor and a soil support value as determined from laboratory CBR tests. For rigid pavement design, the required input is modulus of subgrade reaction.

Flexible Pavement Designs

1972 Flexible Design Equation

$$\log(W_{t18(80kN)}) = 9.36*\log(SN+1) - 0.20 + (G_t/(0.40+(1094/(SN+1)^{5.19}))) + \log(1/R) + 0.372*(SSV-3.0)$$

where:

$W_{t18(80kN)}$ = number of 18 kip (80kN) single axle load applications during design life,

SN = required structural number,

$G_t = \log((4.2-p_t)/2.7)$,

p_t = terminal serviceability,

R = regional factor,

SSV = soil support value.

Rigid Pavement Designs

1972 Rigid Design Equation

$$\log(W_{t18(80kN)}) = 7.35*\log(D+1) - 0.06 + (G_t/(1+(1.624*10^7/(D+1)^{8.46}))) + (4.22-0.32*p_t)* \log((W/215.63*J)*((D^{0.75}-1.132)/(D^{0.75}-(18.42/Z^{0.25}))))$$

where:

$W_{t18(80kN)}$ = number of 18 kip (80kN) single axle load applications during design life,

D = thickness in inches (with dowels)

$G_t = \log((4.5-p_t)/3.0)$,
p_t = terminal serviceability,
Z = E/k

J = continuity factor

k = modulus of subgrade reaction in psi/in = $k_{kPa/mm} \div 0.272$

E = concrete modulus in psi = $E_{kPa} \div 6.895$

W = Working stress in psi = $W_{kPa} \div 6.895$
- factor*concrete modulus of rupture (3rd pt, 28 days)

The following inputs are used for jointed, doweled concrete pavement design:
Design period = 30 years

p_t = 2.5 or 3.0 (see Terminal Serviceability)
J = 2.8 (tied shoulders); 3.2 (asphalt shoulders)

E = 4,200,000 psi
E_{kPa} = 29,000,000 kPa

k = 400 psi/in (drainage layer on stabilized subgrade)
$k_{kPa/mm}$ = 110 kPa/mm.
W = 490 psi
W_{kPa} = 3,400 kPa

For metric designs, the thickness obtained using English units will be converted to metric by multiplying the thickness in inches by 25.4 and rounding the result up to the nearest 10 millimeters.

TRAFFIC

The following traffic information is required for all pavement designs:

Initial ADT	Percent Duals
Projected ADT	Percent TTST

The initial ADT should be updated if it is not within 2 years of the letting date. The projected ADT is normally for a 20-year period, although 30-year projections are needed when structural requirements are high enough to warrant life cycle cost analyses. Until the Traffic Forecast Unit provides 30-year projections, the 20-year growth rate should be used to project traffic counts to the 30-year mark. Traffic loadings are expressed in terms of 18 kip (80 kN) equivalent single axle loads (ESALs) in the AASHTO design equations. Truck weight studies are used to determine "average" loadings for two different truck classifications - Duals and TTST. The term "Duals" represents single unit single axle trucks whereas the term "TTST" represents various combinations of multiple unit and multiple axle trucks. Loadings from automobiles are considered to be negligible. Improvement in our traffic load projections to include a breakdown of additional truck types for 10, 20, and 30 year periods is a desirable near-term goal.

Lane Distribution Factors

No. of Lanes In One direction	Lane Distribution Factor
1	1.0
2	0.9
3 or more	0.8

A lane distribution factor of 0.50 will be used for the design of inside (median) lane widening of existing facilities with 2 or more lanes per direction.

Truck Loading Factors

Flexible Pavement

18 kip (80 kN) ESALs

	DUALS	TTST
Rural Freeway	0.30	1.15
Rural Other	0.30	0.95
Urban Freeway	0.30	0.85
Urban Other	0.25	0.80

Rigid Pavement

18 kip (80 kN) ESALs

	DUALS	TTST
Rural Freeway	0.30	1.60
Rural Other	0.35	1.30
Urban Freeway	0.35	1.20
Urban Other	0.25	1.10

SOIL SUPPORT VALUE

The soil support value to be used in the design equation will be determined from CBR tests. The soil support value is determined from the following equation:

$$SSV = 5.32*\log(CBR) - 1.49$$

The pavement design engineer will consider laboratory CBR test results, Geotechnical Unit recommendations, dynamic cone penetrometer results, and deflection data (if any) in selecting a soil support value for pavement design. The number of CBR tests assigned to each soil type should be proportional to the number of samples at design elevation of that type as determined by qualities. No fewer than three CBR's should be run. The CBR used to determine SSV should be the weighted average according to the proportion of that soil type on the project.

TERMINAL SERVICEABILITY INDEX

The terminal serviceability index (p_t) represents the serviceability of a pavement at the end of the design period. The Present Serviceability Rating (PSR) is based on a rating scale that designates the condition of the pavement at any instant of time. This rating is the average rating of a panel of individuals who rate the pavement on a scale from 0 to 5.0. A rating of 5.0 indicates a "perfect" pavement, whereas a rating of 0 indicates an "impassable" pavement. Selection of p_t is based on the lowest serviceability that will be tolerated before surfacing or reconstruction becomes necessary. A pavement with a terminal serviceability of 2.5 is considered the lowest acceptable rating for a major highway. A terminal serviceability index (p_t) of 2.75 will be used for roadways where the 20-year traffic projection exceeds 50,000 ADT with a high heavy truck volume. A terminal serviceability index of 3.0 will be used for design of all roadways where the 20-year traffic projection equals or exceeds 80,000 ADT with a high heavy truck volume. A terminal serviceability index of 2.5 will be used for the design of all other roadways.

REGIONAL FACTOR

The regional factor will be determined from the attached listing unless a higher regional factor is recommended in the Geotechnical report. Under no circumstances will a lower regional factor be used than that shown. The reason(s) for using a higher regional factor will be documented in the final pavement design recommendation.

REGIONAL FACTORS

County	Factor	County	Factor	County	Factor
Alamance	1.0	Franklin	1.0	Orange	1.0
Alexander	1.0	Gaston	1.0	Pamlico	0.5
Alleghany	1.5	Gates	0.5	Pasquotank	0.5
Anson	1.0	Graham	1.5	Pender	0.5
Ashe	1.5	Granville	1.0	Perquimans	0.5
Avery	1.5	Greene	0.5	Person	1.0
Beaufort	0.5	Guilford	1.0	Pitt	0.5
Bertie	0.5	Halifax	0.5	Polk	1.5
Bladen	0.5	Harnett	0.5	Randolph	1.0
Brunswick	0.5	Haywood	1.5	Richmond	0.5
Buncombe	1.5	Henderson	1.5	Robeson	0.5
Burke	1.5	Hertford	0.5	Rockingham	1.0
Cabarrus	1.0	Hoke	0.5	Rowan	1.0
Caldwell	1.5	Hyde	0.5	Rutherford	1.5
Camden	0.5	Iredell	1.0	Sampson	0.5
Carteret	0.5	Jackson	1.5	Scotland	0.5
Caswell	1.0	Johnston	0.5	Stanly	1.0
Catawba	1.0	Jones	0.5	Stokes	1.0
Chatham	1.0	Lee	0.5	Surry	1.5
Cherokee	1.5	Lenoir	0.5	Swain	1.5
Chowan	0.5	Lincoln	1.0	Transylvania	1.5
Clay	1.5	Macon	1.5	Tyrrell	0.5
Cleveland	1.0	Madison	1.5	Union	1.0
Columbus	0.5	Martin	0.5	Vance	1.0
Craven	0.5	McDowell	1.5	Wake	1.0
Cumberland	0.5	Mecklenburg	1.0	Warren	1.0
Currituck	0.5	Mitchell	1.5	Washington	0.5
Dare	0.5	Montgomery	0.5	Watauga	1.5
Davidson	1.0	Moore	0.5	Wayne	0.5
Davie	1.0	Nash	0.5	Wilkes	1.5
Duplin	0.5	New Hanover	0.5	Wilson	0.5
Durham	1.0	Northampton	0.5	Yadkin	1.0
Edgecombe	0.5	Onslow	0.5	Yancey	1.5
Forsyth	1.0				

LAYER COEFFICIENTS

Layer coefficients used in building a pavement structure to the required structural number are as follows:

Marshall Mix Designs:

	(per in)	(per mm)
Asphalt Concrete Surface Course, Type I-1	0.44	0.017
Asphalt Concrete Surface Course, Type I-2	0.44	0.017
Asphalt Concrete Surface Course, Type HDS	0.44	0.017
Asphalt Concrete Binder Course, Type H	0.44	0.017
Asphalt Concrete Binder Course, Type HDB	0.44	0.017
Asphalt Concrete Base Course, Type HB	0.30	0.012

Superpave Mix designs:

Asphalt Concrete Surface Course, Type S9.5X	0.44	0.017
Asphalt Concrete Surface Course, Type S12.5X	0.44	0.017
Asphalt Concrete Intermediate Course, Type I19.0X	0.44	0.017
Asphalt Concrete Base Course, Type B25.0X	0.30	0.012
Asphalt Concrete Base Course, Type B37.5C	0.30	0.012

Other Materials:

Permeable Asphalt Drainage Layer (PADL)	0.14	0.0055
Aggregate Base Course (ABC)	0.14	0.0055
Cement Treated ABC (CTABC)	0.23	0.009
Cracked and Seated Concrete	0.28*	0.011
Rubblized Concrete	0.28*	0.011
	(for layer)	(for layer)
200 mm (8") Lime Stabilized Subgrade	1.0	1.0
-or-		
175 mm (7") Cement Stabilized Subgrade	1.0	1.0

* Monitoring of existing projects may result in changes to layer coefficients for crack and seat and rubblization.

HEAVY DUTY MIXES (Marshall Mix Designs)

Heavy duty surface (HDS) and heavy duty binder (HDB) mixes will be specified when the total 18 kip (80 kN) equivalent single axle loads equal or exceed one million in the design lane. I-1 and H surface and binder mixes are specified when the loadings are less than one million in the design lane. Other mixes, including I-2 mixes will be considered on a project by project basis when requested by the Division. All requests should be directed in writing from the Division to the State Pavement Management Engineer.

LOADING LEVELS (Superpave Mix Designs)

The letter designation at the end of Superpave mix designs indicates the level of loading expected in a 20 year design period. When designing for shorter durations, the selection of loading level should be based on the 20 year accumulation of ESAL's.

The selection of asphalt binder grade for Superpave mixes is dependent on loading level. The PG grade increases as a function of loading level and proximity to the surface of the pavement structure.

Superpave loading designations and binder grade requirements are as follows.

Mix Type	Loading Range (Million ESAL's)	Asphalt Binder Grade
Surface		
S9.5A	Less than 0.3	PG64-22
S9.5B	Less than 3.0	PG64-22
S9.5C	3 to 10	PG70-22
S12.5B	Less than 3.0	PG64-22
S12.5C	3 to 30	PG70-22
S12.5D	Over 30	PG76-22
Intermediate		
I19.0B	Less than 3.0	PG64-22
I19.0C	3 to 30	PG64-22
I19.0D	Over 30	PG70-22
Base		
B25.0B	Less than 3.0	PG64-22
B25.0C	3 or Greater	PG64-22
B37.5C	3 or Greater	PG64-22

UNIT WEIGHTS; APPLICATION RATES

Pavement Item	Wt lbs/sy-in.	kg/m^2-mm
I-1	110	2.35
I-2	105	2.25
HDS	112	2.40
HDB	112	2.40
H	110	2.35
HB	110	2.35
S9.5X	112	2.40
S12.5X	112	2.40
I19.0X	114	2.45
B25.0X	114	2.45
B37.5C	114	2.45
F-1	100	2.15
PADL	90	1.90
ABC	150 $lbs./ft^3$	2400 kg/m^3
CTABC (3.5%Cement)	150 $lbs./ft^3$	2400 kg/m^3

Asphalt Cement Percentages

Marshall Mix Designs:

Division	I-1	I-2	H	HDS	HDB
1	5.5	6.6	5.0	5.2	4.8
2	6.0	6.7	5.4	5.7	5.2
3	5.8	6.7	5.6	5.5	5.4
4	5.7	6.4	5.0	5.4	4.8
5	5.9	6.6	5.2	5.6	5.0
6	5.3	6.3	5.0	5.0	4.8
7	6.0	6.6	5.2	5.7	5.0
8	5.6	6.5	5.0	5.3	4.8
9	6.0	6.9	5.2	5.7	5.0
10	5.8	6.4	5.0	5.5	4.8
11	6.2	6.9	5.2	5.9	5.0
12	5.7	6.6	5.0	5.4	4.8
13	6.2	7.0	5.4	5.9	5.2
14	6.2	7.0	5.1	5.9	4.9

Asphalt concrete base course, Type HB 4.0%

Superpave Mix Designs:

Asphalt Concrete Surface Course, Type S9.5X	6.5%
Asphalt Concrete Surface Course, Type S12.5X	5.5%
Asphalt Concrete Intermediate Course, Type I19.0X	4.7%
Asphalt Concrete Base Course, Type B25.0X	4.3%
Asphalt Concrete Base Course, Type B37.5C	4.3%

Other Materials:

Permeable asphalt drainage course, Type P-57	2.0%
Sand asphalt base, Type F-1	6.0%
Sand asphalt surface, Type F-1	7.0%

Non-strip Additive................. 10 lbs per ton (5.0 kg per Metric Ton) of asphalt cement

Prime Coat............................ to be used on all pavements with aggregate bases with 2.5 inches (60 mm) or less of Asphalt surfacing at a rate of 0.35 gal. / sy (1.58 L/m^2.)

Asphalt Curing Seal........ for CTABC, Soil cement, and lime treated soil at a rate of 0.15 gal. / sy (0.679 L/m^2).

Blotting Sand

PAVEMENT LAYER DEPTHS

Layer Type	Maximum Layer Depths		Single Lift Depths	
	Inches	Millimeters	Inches	Millimeters
HDS	2.5	60	1.25 to 1.75	30 to 45
I-1, I-2	2	50	1 to 1.5	25 to 40
HDB	4.5 (to match curb &gutter: 3.5 otherwise	115 (to match curb & gutter) 90 otherwise	1.75 to 3.5	45 to 90
H	3	75	1.5 to 3	40 to 75
HB	No restrictions	No restrictions	3 to 5.5	75 to 140
S9.5X	2.5	60	1.0 to 1.5 1.25 for TIP	25 to 40 30 for TIP
S12.5X	3.0	70	1.5 to 2.25.	35 to 60
I19.0X	4	110	2.25 to 4	55 to 110
B25.0X	No restrictions	No restrictions	3 to 5.5	75 to 140
B37.5C	No restrictions	No restrictions	4.5 to 6	115 to 150
ABC	12 normal increments are 6, 8, 10, 12	300 normal increments are 150, 200, 250, 300	8	200
CTABC	8 (plant mixed) 7 (road mixed)	200 (plant mixed) 175 (road mixed)	8	200

Any deviations from these depths will be noted on the pavement design letter.

To "build" a structural number, as much of the structural number as possible will be put into the surface and binder layers. In other words, the depths of these two layers will be maximized. For normal mixes, this total depth is 5 in (130 mm) and for heavy duty mixes, the total depth is 6 in (150 mm). For curb and gutter sections, the total binder and surface depth will be increased to 7 in. (180 mm) to match curb depth. When less than 4 in. (100 mm) of HB is used under curb and gutter, Asphalt Curing Seal and Blotting Sand will be recommended for low areas that collect water during construction. We will normally use 8 in (200 mm) of ABC as the starting depth for aggregate base.

THIN-DEPTH PAVED SHOULDER DESIGN

For paved shoulders that will not be constructed with full depth of travel lane pavement thickness (see Roadway Design Paved Shoulder Policy), 2 % of the design lane traffic loads will be used for design.

PAVEMENT DESIGNS FOR DETOURS

Pavement designs for detours and other temporary pavements will usually be constructed of aggregate base course (ABC) and minimal asphalt depths to reduce construction waste. ABC recovered from detour structures will be re-used in the project or stockpiled to be used by Division Maintenance Forces. Typical design periods are from 6 months to 2 years as provided by Project Design Engineer. Pavement designs prepared for design periods of less than 6 months should be carefully reviewed since required structural numbers may be unreasonably low. For any detour that is expected to carry truck traffic, the minimum asphalt layer shall be 2 inches.

Note: The selection of loading level for SuperPave mixes will be based on the theoretical 20 year accumulation of ESAL's even when the design life used for the pavement structure is for a short duration.

BRIDGE REPLACEMENT PAVEMENT DESIGNS

Due to the small amount of roadway work involved in most of these projects, final pavement designs for bridge replacement projects are typically made without a soils investigation or review committee input. Soil support values are determined as described in the section "Preliminary Pavement Designs." On bridge replacement projects with roadway work less than 1200 ft (400 m) in length, a full depth asphalt design is normally recommended. For lengths in excess of 1200 ft (400 m), an aggregate base course (ABC) will be provided if feasible. All of these designs are to be based on a 20-year design period. If there is an exception, the reason(s) for the exception should be documented on the final pavement design issued to the Roadway Design or Design Services Project Engineer. Traffic counts should to be updated if they are more than 2 years from the letting date.

Selection of the either the appropriate Superpave or Marshall mix designs should be made from the design tables found in the appendix. Recommended bridge replacement pavement designs are included in Appendix A as follows:

Table A-1 - Recommended full-depth Superpave designs
Table A-2 - Recommended ABC Superpave designs
Table A-3 - Recommended full-depth Marshall designs
Table A-4 - Recommended ABC Marshall designs

REHABILITATION DESIGNS

Emphasis for rehabilitation designs is to be placed on structural evaluation of the existing pavement. In addition to the normal investigation of these projects by the Geotechnical Unit, all pavement designs will require the following information:

1. Cores of existing pavement structure - to determine thickness of layers, assign structural layer coefficients, and conduct laboratory tests as needed.

2. Temperature and FWD deflection data at least every 500 ft. (150 m.) in outside wheel path of outside lane to include all core locations. Spacing of tests should result in at least 20 data points.

3. Dynamic Cone Penetrometer (DCP) evaluations to a minimum depth of 24 in. (600 mm) (through stone base, if present, and into subgrade at core locations) as permitted by traffic control and safety considerations.

For rehabilitation designs requiring asphalt overlays, the design period will be 10 years. DCP, FWD, and lab test data in addition to Geotechnical recommendations will be used to determine the existing soil support conditions. Present and 10 year projected traffic figures are to be used to determine the number of 18 kip (80 kN) axle loads during the design period and the required SN. With this information, three overlay thickness determinations may be prepared as follows:

Design 1 - Condition Survey Method

The existing SN of the pavement is determined from the condition survey and core data. The overlay thickness is determined from:

Overlay SN = Required SN - Existing SN

The existing SN will be determined by the pavement design engineer by assigning layer coefficients to the pavement layers after examination of cores. DCP data will be utilized to determine the depth and layer coefficient for aggregate base. Chapter 5 of the AASHTO Guide provides general guidelines for assignment of layer coefficients based upon pavement surface distress. The layer SN is obtained by multiplying the layer thickness by its assigned layer coefficient. The existing SN is the sum of all layer SN's in the pavement structure. The required SN is the SN needed to support the 10 year projected traffic, with the difference in these two structural numbers being the structural deficiency or overlay requirement.

Design 2 - Effective Structural Number

The effective structural number of the pavement structure will be determined from FWD data as outlined in the Chapter 5 rewrite of the 1986 AASHTO Design Guide.

Effective SN = 0.0045*D*(Ep)^(1/3)

where,

D = total depth of pavement structure (in.)
(total pavement depth above subgrade)
D_{mm} = total depth of pavement structure (mm) = D *25.4
Ep = effective modulus of pavement layer (psi) = $Ep_{kPa} \div 6.895$
(from temperature corrected deflection data)
Ep_{kPa} = effective modulus of pavement layer (kPa)

Overlay SN = Required SN - Effective SN

Design 3 - Effective Modulus

The number of 18 kip (80kN) axle loads during the 10 year design period is calculated and the target deflection is determined from one of the following equations:

Dt = 10^((log(9.3*10^9/Wt18)/3.34)) (ABC)
or, Dt = 10^((log(5.6*10^11/Wt18)/4.6)) (Full depth asphalt)

where:

Dt = target FWD deflection (mils) (desired deflection limit),
$Dt_{\mu m}$ = target deflection (micrometers) = Dt * 25.4
W_{t18} = number of 18 kip (80 kN) single axle load applications during the 10 year design period

Deflection under the load plate is temperature corrected (currently requires air, pavement surface temperature, and thickness of asphalt). The overall modulus of the entire pavement structure is determined from the temperature corrected deflection by using the Boussinesq equation for a one layer structure:

$$Modulus = 2*1000*P*(1-\mu^2)/(ã* r *D0)$$

where,

P = FWD load (lbs) = P_N * 0.2248
P_N = FWD load (N)
μ = Poisson's ratio
r = radius of loaded area (in.) = $r_{mm} \div 25.4$
r_{mm} = radius of loaded area (mm)
ã = 3.14159...
D0 = Temperature corrected deflection under load plate (mils)
= $D0_{\mu m}$ * 0.03937
$D0_{\mu m}$ = D0 (micrometers)

For the FWD with a 5.905" (150 mm) radius load plate and Poisson's ratio = 0.35 for the single layer, this equation reduces to:

$$Modulus (psi) = 94.596*P \div D0$$

Now, by using Odemark's transformation for a 2 layer system, one can determine overlay thickness by calculating the depth of 500,000 psi (3500 MPa) surfacing required to reduce the load plate deflection to the target deflection. In this analysis, the following equation is solved for D:

$$Dt = 851,360*(D1+D2)$$

where,

Dt = target deflection (mils)

D1 = 1/(Modulus*(1+((D/r)*((Ep/Modulus)^(1/3)))^2)^0.5)
D2 = (1-(1/((1+(D/r)^2)^0.5)))/Ep

r = FWD load plate radius = 5.9055 in. (150 mm).
Ep = 500,000 psi (overlay modulus)
Ep_{MPa} = 3500 MPa
D = overlay thickness (in.)
D_{mm} = Dt*25.4 (mm)
Modulus = overall pavement modulus (one layer modulus representing entire pavement structure and subgrade) (psi)
$Modulus_{MPa}$ = Modulus * 0.006895 (MPa)

All three design procedures may be evaluated by the Pavement Analysis Engineer for each project before providing a design recommendation. Design method 3 is preferred due to larger statistical sample over full project length. In order to accommodate clearance limitations under structures the design thickness may be reduced by utilizing additives in the asphalt mix.

PAVEMENT DRAINAGE

Drainage Sublayers

Rigid pavements will typically be constructed utilizing an asphalt stabilized layer under the concrete layer in order to provide uniform support and positive drainage.

Shoulder Drains

Shoulder drains will be used continuously when permeable asphalt drainage layers are used. Shoulder drains will be considered for all projects with average daily traffic (ADT) of 15,000 and heavy truck percent greater than 5%. For projects with average daily traffic of 50,000 and heavy truck percent greater than 15%, shoulder drains are highly recommended. Shoulder drains will typically be recommended for locations with flat grades (less than 1%), vertical curves, and poorly draining soils. Aggregate shoulder drains are typically used in new projects. Geocomposite shoulder drains may be used adjacent to existing pavements on rehabilitation projects.

Outlets

Outlets are generally located at 300' (100 m) intervals. Wherever possible, outlets are tied in to drainage structures. When outlets are placed on fill or ditch slopes, a concrete pad is used to protect the end of the outlet pipe. Outlet locations are imprinted at the edge of concrete pavements and are marked with white triangles painted at the pavement edge on asphalt surfaces.

UNIT COSTS

The unit costs for pavement pay items are obtained from the Design Services Unit. The request for unit costs should include the project location and description and a complete listing of pay items and corresponding total quantities.

LIFE CYCLE COST ANALYSIS

Life cycle cost analyses will be conducted for all projects in which both flexible and rigid pavements are considered. This cost analysis will typically be required on all projects where the structural number equals or exceeds 6.0. The analysis period, discount rate, and type of analysis are as follows:

Analysis period:	30 years
Discount rate:	4%
Type of analysis:	Present worth

The cost analyses will include the following items:

1. Initial construction cost estimate for full typical section (This includes estimated construction costs for the pavement structure to include all pavement structure items for the main line and shoulders).
2. Future rehabilitation costs at 10 and 20 year time periods (see Life Cycle Strategies).

The following items are typically not available but will be included in the life cycle cost analyses if they are available on a project-by-project basis or if there is a known difference in these costs between alternates:

1. User costs
2. Annual maintenance costs
3. Traffic control costs
4. Salvage value

All costs included in the analyses will be clearly noted in the review sheets for the project that are issued to Division Engineers and all Pavement Review Committee members.

LIFE CYCLE STRATEGIES

Life cycle cost analyses will include the following estimated present worth values:

Flexible Pavement

Initial cost:	Cost to construct 20 year structural requirement
10 year cost:	Cost to mill and replace surface course
20 year cost:	Cost to mill and replace surface course Cost to provide additional overlay depth to meet 30 year structural requirement.

Rigid Pavement

Initial cost:	Cost to construct 30 year structural requirement
10 year cost:	Cost to saw and seal joints
20 year cost:	Cost to saw and seal joints

The example format shown below should be followed for presenting the life cycle cost data to the Pavement Review Committee:

Life Cycle Strategies (Example)

Design	10 year treatment	20 year treatment
1 (Flexible)	Mill 2.5" (60 mm) Replace 2.5" (60 mm)	Mill 2.5" (60 mm) Overlay w/4.5" (110 mm) asphalt
2 (Rigid)	Saw, reseal joints	Saw, reseal joints

Life Cycle Cost Summaries
Discount rate = 4%

	Design 1	Design 2
Initial Construction	$378.15	$368.35
10 year treatment	$58.10	$14.50
10 year present worth	$39.25	$9.80
20 year treatment	$119.58	$27.16
20 year present worth	$54.58	$12.40
30 year life cycle present worth	$471.98	$390.55

PAVEMENT TYPE SELECTION

Many factors influence the decision making process for pavement type selection. The process will closely follow the type selection guidelines as presented in Appendix B of the 1993 Guide for the Design of Pavement Structures. Factors that influence the selection process include:

1. Traffic,
2. Soils characteristics,
3. Weather,
4. Construction consideration,
5. Recycling,

6. Cost comparison,
7. Pavement performance,
8. Adjacent existing pavements,
9. Conservation of materials and energy,
10. Availability of local materials or contractor capabilities,
11. Traffic safety,
12. Incorporation of experimental features,
13. Stimulation of competition, and
14. Municipal preference, local government preference, and recognition of local industry.

PRELIMINARY PAVEMENT DESIGNS

Preliminary pavement designs will be prepared by the Pavement Design Engineer when requested from either the Roadway Design or Design Services Unit. These requests will normally be more than one year from the anticipated letting date. The soil support value used for preliminary design purposes will be dependent upon the regional factor. If the regional factor is either 0.5 or 1.5, a representative CBR value of 9 (SSV=3.59) will be used. For a regional factor of 1.0, a representative CBR value of 6 (SSV=2.65) will be used. All preliminary designs will specify ABC (aggregate base course) unless narrow widening (6 ft (1.8 m) or less) is planned; in this case, a full depth asphalt design will be provided. The Roadway or Design Services Project Engineer will be provided with a preliminary pavement design.

FINAL PAVEMENT DESIGNS

Final pavement designs will be prepared upon receipt of the Geotechnical Report for the project. This should be no later than 8 months prior to letting. If the structural number (SN) equals or exceeds 6.0, then both rigid and flexible pavement designs are to be prepared. Quantity estimates are to be prepared and submitted to the Design Services Unit for unit cost estimates. From these cost estimates, a per foot (meter) cost for the predominant typical section is to be determined. Typical cost comparisons are to be made between full depth asphalt and aggregate bases. If the structural requirements are high enough, then cost analyses will also include cement treated bases and rigid pavements. For CTABC designs to be considered a minimum asphalt depth of 5" (120 mm) will be required. Roadways with either high truck percentages or heavy loading conditions coupled with poor subgrade support capacity will require much higher structural requirements for consideration of CTABC designs.

Alternate pavement designs considered will be summarized in a "review sheet" for the project which will include reasons for final pavement design recommendations. Emphasis on determining the recommended design is to be placed on life cycle cost analyses. Reasons for recommendations by the pavement design engineer include but are not limited to: initial construction cost, life cycle cost, performance history, traffic control, safety, and ease of construction. Both initial and life cycle cost differences are not considered significant unless they exceed 5 %. Designs will be presented and discussed at a monthly Pavement Review Committee meeting to aid the Pavement Design Engineer in selecting the final pavement design.

PAVEMENT REVIEW COMMITTEE

The Pavement Review Committee meets on the last Thursday of each month at 1:30 P.M. Target review dates are 7 to 8 months prior to scheduled letting (turn in date for consultants). Members of the review committee consist of representatives from the following units:

Construction
Design Services
Division
FHWA
Geotechnical
Maintenance
Pavement Management
Program & Policy
Roadway Design
Traffic Control

Invitations are extended to Division Engineers and/or their representatives for all projects.

FINAL PAVEMENT DESIGN LETTER

After the Review Committee meeting, the State Pavement Management Engineer will furnish a final pavement design letter to the Roadway or Design Services Project Engineer containing pavement designs for main line, Y-lines, ramps, loops, collectors, service roads, paved shoulders and all other traffic bearing areas as needed.

Appendix

Table A-1 Recommended Bridge Replacement Pavement Designs - (Superpave, Full-Depth Asphalt)

Structural Number Range	English Units (Inches)				Metric Units (Millimeters)			
	S9.5 X	I19.0 X	B25.0X	Structural Number	S9.5 X	I19.0 X	B25.0X	Structural Number
< 1.70	1.5		3.50	1.71	40.00		85.00	1.7
1.71 - 2.05	2.50		3.00	2.00	60.00		80.00	1.98
2.06 - 2.36	2.50		4.00	2.30	60.00		110.00	2.34
2.36 - 2.60	2.50		5.00	2.60	60.00		130.00	2.58
2.61 - 2.80	2.50		5.50	2.75	60.00		140.00	2.70
2.81 - 3.10	2.50	2.50	3.00	3.10	60.00	60.00	80.00	3.00
3.11 - 3.20	2.50	2.25	3.50	3.14	60.00	55.00	100.00	3.15
3.21 - 3.40	2.50	2.50	4.00	3.40	60.00	60.00	110.00	3.36

Table A-2 Recommended Bridge Replacement Pavement Designs - (Superpave, ABC)

Structural Number Range	English Units (Inches)				Metric Units (Millimeters)			
	S9.5 X	I19.0 X	ABC	Structural Number	S9.5 X	I19.0 X	ABC	Structural Number
< 1.85	1.50		8.00	1.78	40.00		200.00	1.78
1.85 - 2.04	2.50		6.00	1.94	60.00		200.00	2.12
2.05 - 2.45	1.25	2.25	6.00	2.38	30.00	60.00	150.00	2.36
2.46 - 2.81	1.25	2.50	8.00	2.77	30.00	70.00	200.00	2.80
2.81 - 3.10	2.50	2.50	6.00	3.04	60.00	70.00	150.00	3.04
3.11 - 3.21	2.50	2.25	8.00	3.21	60.00	60.00	200.00	3.14
3.22 - 3.40	2.50	2.50	8.00	3.32	60.00	90.00	150.00	3.38