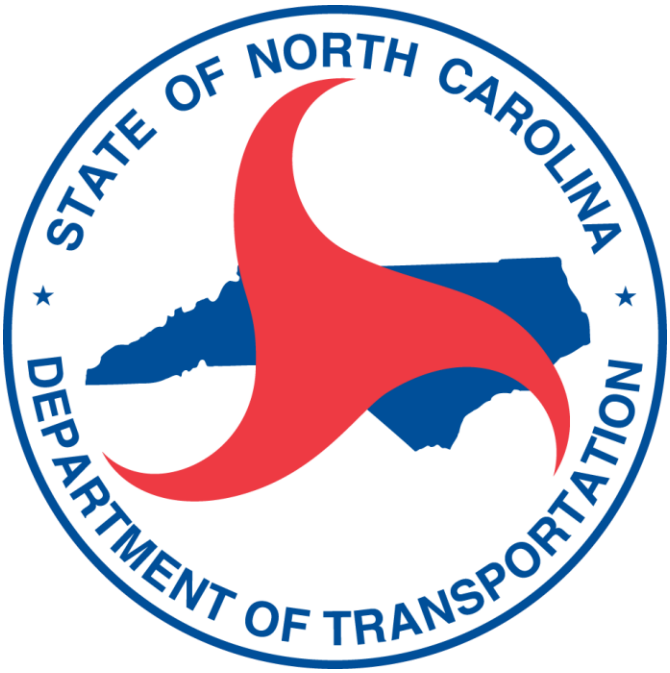
NCDOT

PAVEMENT DESIGN PROCEDURE

AASHTO 1993 METHOD



N. C. Department of Transportation

Materials and Tests Unit – Pavement Section

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INTRODUCTION

The pavement design guidelines included herein are to be used for the design of all new and rehabilitated projects 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.

PAVEMENT DESIGN EQUATIONS

The AASHTO design equations as presented in the AASHTO Interim Guide for Design of Pavement Structures, 1993 are to be used for the design of both flexible and rigid pavements.

Flexible Pavement Designs

1993 Flexible Design Equation

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

W_{18} = predicted number of 18-kip equivalent single axle load applications

Z_R = standard normal deviate

S_o = combined standard error of the traffic prediction and performance prediction

ΔPSI = difference between the initial design serviceability index, p_o, and the design terminal service index, p_t

M_R = resilient modulus (psi)

SN = structural number required of the total pavement thickness. Design SN must be within 0.10 of this SN Required.

The following inputs are used for flexible pavement design:

Design period = 30 years*

*A 20 year design is to be used on secondary roads with the ADT is less than 20,000 and no LCCA is needed.

p_o = 4.20

p_t = see Terminal Serviceability (pg. 4)

S_o = 0.45

Z_R = see Reliability (pg. 5)

M_R = if no resilient modulus is available use following equation to convert CBR values

$$M_R = 2555 * (CBR\ VALUE)^{0.64}$$

Rigid Pavement Designs

1993 Rigid Design Equation

$$\log(W_{18}) = Z_R * S_o + 7.35 * \log(D+1) - 0.06 + \frac{\log\left[\frac{\Delta PSI}{4.5-1.5}\right]}{1+\frac{1.624*10^7}{(D+1)^{8.46}}} + (4.22 - 032 * p_t) * \log\left[\frac{S_c' * C_d * (D^{0.75}-1.132)}{215.63 * J\left[D^{0.75} - \frac{18.42}{(E_c/k)^{0.25}}\right]}\right]$$

W_{18} = predicted number of 18-kip equivalent single axle load(ESALS) applications

Z_R = standard normal deviate

S_o = combined standard error of the traffic prediction and performance prediction

D = thickness (inches) of pavement slab

ΔPSI = difference between the initial design serviceability index, p_o, and the design terminal service index, p_t

S'_c = modulus of rupture (psi) for Portland cement concrete used on a specific project

J = load transfer coefficient used to adjust for load transfer characteristics of a specific design

C_d = drainage coefficient

E_c = modulus of elasticity (psi) for Portland cement concrete

K = modulus of subgrade reaction.

The following inputs are used for concrete pavement design:

Design period = 30 years
p_o = 4.50
p_t = see Terminal Serviceability (pg. 4)
S_o = 0.35
Z_R = see Reliability (pg. 5)
J = 2.8 (tied PCC shoulders) or 3.2 (asphalt or RCC shoulders) If outside lanes are widened to 13' a value of 2.8 can be used with any shoulders.
E = 3,500,000 psi
K = 400 psi/in (drainage layer on stabilized subgrade) or 200 psi/in (ABC)
C_d = 1.0
S'_c = 650 (psi)

TRAFFIC ESALS

The following traffic information is required for all pavement designs:

Initial ADT	Percent Duals
Projected ADT	Percent TTST

If the traffic forecast is more than 2 years old check to see if updated traffic information is available from the Traffic Forecasting Unit. The projected ADT is normally for a 20-year period, although 30-year projections are needed for pavement design and life cycle cost analyses. Unless 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. The minimum growth rate used for designs is 2.0%, unless the Traffic Forecast Unit provides a lower rate. Traffic loadings are expressed in terms of 18 kip 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. Design values of 2% Duals and TTST 1% are considered minimums. Equations for growth rates and ESALS are listed below.

$$\%Growth = (10^{\wedge(\frac{\log_{10}\left(\frac{ADT_{Future}}{ADT_{Initial}}\right)}{(Year_{Future}-Year_{Initial})*365.25})} * 365.25 - 365.25) * 100$$

$$ADT_C = ADT_{Initial} * (1 + \frac{\%Growth}{100 * 365.25})^{\wedge((Year_{Constrution}-Year_{Intial})*365.25)}$$

$$ESALS_{Total} = \frac{((1+\frac{\%Growth}{100*365.25})^{(365.25*N_D)}-1)*(ADT_C*\frac{\%TTST}{100}*TTST_F+ADT_C*\frac{\%Duals}{100}*Dual_F)*\frac{\%Direction}{100}*L_D}{\ln(1+\frac{\%Growth}{100*365.25})}$$

N_D=Design Number of Years
ADT_C = Average Annual Daily Traffic in the year of construction.
$TTST_F$= TTST Loading Factor
$Dual_F$ = Duals Factor

Lane Distribution Factors (L_D)

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 ESALs

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

Rigid Pavement

18 kip ESALs

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

Rural – Any area that is mostly long distance trucks. (Typically this is outside city limits)
Urban – Any area that is mostly delivery area trucks. (Typically this is inside city limits or industrial area)

% Direction

A Direction spilt of 50% is typically used in all designs. Even if a different peak hour direction is given on the plans, we assume that traffic throughout the day will equal 50% in each direction.

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 40,000 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.

20 Year ADT	**Terminal Serviceability Index**
80,000 or Larger	3.00
40,000 or Larger	2.75
Lowest Acceptable	2.50

Reliability

Design reliability is defined as the probability that a pavement section will perform satisfactorily over the design period. It must account for uncertainties in traffic loading, environmental conditions, and construction materials. The AASHTO design method accounts for these uncertainties by incorporating a reliability level R to provide a factor of safety into the pavement design and thereby increase the probability that the pavement will perform as intended over its design life. The reliability level is not included directly in the AASHTO design equations. Rather, it is used to determine the standard normal deviate Z_R. The levels of reliability recommended by NCDOT for various classes of roads are listed below.

Road Types	Reliability	Z_R
Interstate and Freeways*:	95	-1.645
Primary:	90	-1.282
Secondary with >20,000AADT:	90	-1.282
Secondary: with <20,000AADT	85	-1.036

*All Freeways should have 95% Reliability, even if they are a Primary or Secondary Road.

LAYER COEFFICIENTS

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

Superpave Mix designs:

	(per inch)
Asphalt Concrete Surface Course, Type S9.5X	0.44
Asphalt Concrete Intermediate Course, Type I19.0C	0.44
Asphalt Concrete Base Course, Type B25.0C	0.30

Other Materials:

Permeable Asphalt Drainage Course (PADC)	0.14
Aggregate Base Course (ABC)	0.14
Cement Treated ABC (CTABC)	0.23
Cracked and Seated Concrete	0.28*
Rubblized Concrete	0.28*
Full Depth Reclaimed Asphalt	0.20*
	(for layer)
200 mm (8") Lime Stabilized Subgrade	1.0
-or-	
175 mm (7") Cement Stabilized Subgrade	1.0

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

LAYER COEFFICIENTS FOR EXISTING PAVEMENT

When calculating the structural number for existing pavements, the layer coefficients should be decreased to determine the effective strength provide of the existing pavement. The amount of reduction is based on the surface condition of the existing pavement. Suggested layer coefficients are given in the 1993 AASHTO Design Guide on Table 5.2.

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. For surface mixtures, the PG grade increases as a function of loading level.
Superpave loading designations and binder grade requirements are as follows.

Mix Type	Loading Range (20 Year Million ESAL's)	Asphalt Binder Grade
Surface		
S9.5B	Less than 3.0	PG64-22
S9.5C	3 to 30	PG64-22
S9.5D	Over 30	PG76-22
Intermediate		
I19.0C	All	PG64-22
Base		
B25.0C	All	PG64-22

UNIT WEIGHTS; APPLICATION RATES

Pavement Item	Wt lbs/sy-in.
S9.5B	110
S9.5C, S9.5D	112
I19.0C	114
B25.0C	114
PADC	90

ABC	150 Lbs./CF
CTABC (3.5% Cement)	150 Lbs./CF

Asphalt Cement Percentages

Superpave Mix Designs:

Asphalt Concrete Surface Course, Type S9.5B	6.7%
Asphalt Concrete Surface Course, Type S9.5C	6.0%
Asphalt Concrete Surface Course, Type S9.5D	5.7%
Asphalt Concrete Intermediate Course, Type I19.0C	4.8%
Asphalt Concrete Base Course, Type B25.0C	4.5%

Other Materials:

Permeable asphalt drainage course, Type P-57	2.5%
Permeable asphalt drainage course, Type P-78	3.0%
OGAFC, Type FC-1	6.1%

Non-strip Additive.....	10 lbs per 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
Asphalt Curing Seal.....	for CTABC, Soil cement, and lime treated soil at a rate of 0.15 gal. / sy

PAVEMENT LAYER DEPTHS

Max layer depths: Inches

S9.5X = 3.0
I19.0C = 4.0
B25.0C = no restrictions
ABC = normally limited to 12, recommended depths are typically 6*, 8, 10, and 12 inches.
*Typically Secondary Roads.
CTABC = 8 for plant mixed; for road mixed 8 with top 7 mixed.

Single lift depths: Inches

S9.5B = 1.0 to 1.5
S9.5C,D = 1.5* to 2.0
*1.0" may be used in wedging only
I19.0C = 2.5 to 4.0
B25.0C = 3.0* to 5.5
*For B25.0C placed on unstabilized subgrade, the minimum lift thickness is 4.0.
ABC = 6* to 10
*8" Preferred minimum on unstabilized subgrade for primary & greater roadways.
CTABC = 8
FDR = 12

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 intermediate layers. In other words, the depths of these two layers will be maximized.

For normal mixes this total depth is 5-5.5 in, and for heavy duty designs the total depth is 6 in. 7 in. of surface and intermediate depth is typically required on interstate designs.

For curb and gutter and expressway gutter sections, the total surface and intermediate depth will be increased to 7 in. to match curb depth. For shoulder berm gutter sections, the total surface and intermediate depth will be set to match gutter depth.

Two lifts of surface mix is standard for almost all designs. 1.25" or 1.5" of S9.5B and 1.5" of S9.5C/S9.5D are the typical lift depths. An asphalt base, ABC base, or CTABC base is required on all flexible pavement designs. Normally 8 in of ABC is used as the starting depth for aggregate base.

Prime Coat is required to be used where surface mixes is placed directly on top of ABC.

MINIMUM DEPTHS FOR PAVEMENT DESIGNS

Minimum Structure Depths that are Recommended for NCDOT Designs				
	Interstate & Freeways	Primary and Secondary >20,000ADT	Primary <20,000ADT	Secondary <20,000ADT
Full Depth Asphalt	11.0" Asphalt	9.5" Asphalt	7.0" Asphalt	6.5" Asphalt
ABC	7.0" Asphalt and 8" ABC	5.5" Asphalt and 8.0" ABC	3.0" Asphalt and 8.0" ABC	2.5" Asphalt and 6.0" ABC
CTABC	7.0" Asphalt and 8.0" CTABC	5.5" Asphalt and 8.0" CTABC	3.0" Asphalt and 8.0" CTABC	2.5" Asphalt and 8.0" CTABC
Concrete	9.0" Concrete 3.0" of PADC 1.25" of S9.5B**	8.0" Concrete 3.0" of PADC 1.25" of S9.5B**	7.0" Concrete 3.0" of PADC 1.25" of S9.5B**	5.0-6.0" Concrete* and 4.0" ABC

*5.0" is the minimum on residential subdivision streets only.
*5.5" is the minimum on collector roadways.
*6.0" is the minimum on Poor to Fair subgrade type (A-4 to A-7)
** For pavements with <2000 average daily trucks 6" ABC can be used rather than the PADC and S9.5B

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. Surface mix is required to be the top layer is any flexible design including detours and temporary pavements.

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, with the exception of D mix types, which will be replaced with a C mix.

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.

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. On bridge replacement projects with roadway work less than 1,200 ft in length, a full depth asphalt design is normally recommended. For lengths in excess of 1,200 ft, an aggregate base course (ABC) will be provided if feasible. All of these designs are to be based on a 20 or 30 year design period, based on ADT. 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. Overlay designs on existing pavement should consist of one to two lifts of surface and based on the condition of the existing roadway. Recommended bridge replacement pavement designs are listed on next page, as low volume designs.

RECOMMENED LOW VOUME PAVEMENT DESIGNS

This table is an easy method to determine designs typically used for low volume pavements, based on required SN (Page 1). Minimum pavement depths based on road types (page 10) still are required, regardless of this table.

****CHECK DESIGN MEETS MINIUM DEPTHS FOR PAVEMENT DESIGNS (PAGE 10)****

Without Curb and Gutter Designs:

(Determine if load level is B, C, or D by using the 20 year ESALS - Page 7)

Table A-1 Recommended Pavement Design - (Full Depth)				
Required Structural Number	**Surface**	**Inter.**	**Base**	**Structural Number Provided**
B LEVEL DESIGNS (Use when 20 year ESALS are <0.3 Million)				
<2.37	2.5” S9.5B		4.0” B25.0C	2.30
2.38 - 2.52	2.5” S9.5B		4.5” B25.0C	2.45
2.53 - 2.67	2.5” S9.5B		5.0” B25.0C	2.60
2.68 - 2.82	2.5” S9.5B		5.5” B25.0C	2.75
2.83 - 3.47	2.5” S9.5B	2.5” I19.0C	4.0” B25.0C	3.40
B, C, & D LEVEL DESIGNS (Use when 20 year ESALS are >0.3 Million)				
<2.59	3.0” S9.5X		4.5” B25.0C	2.52
2.60 - 2.74	3.0” S9.5X		4.5” B25.0C	2.67
2.75 - 2.89	3.0” S9.5X		5.0” B25.0C	2.82
2.90 - 3.04	3.0” S9.5X		5.5” B25.0C	2.97
3.05 - 3.69	3.0” S9.5X	2.5” I19.0C	4.0” B25.0C	3.62
3.70 - 3.84	3.0” S9.5X	2.5” I19.0C	4.5” B25.0C	3.77
3.85 - 3.99	3.0” S9.5X	2.5” I19.0C	5.0” B25.0C	3.92
4.00 - 4.14	3.0” S9.5X	2.5” I19.0C	5.5” B25.0C	4.07

(Determine if load level is B, C, or D by using the 20 year ESALS - Page 7)

Table A-2 Recommended Pavement Design (ABC)				
Required Structural Number	**Surface**	**Inter.**	**Base**	**Structural Number Provided**
B LEVEL DESIGNS (Use when 20 year ESALS are <0.3 Million)				
<2.01	2.5” S9.5B *****		6” ABC	1.94
2.02 - 2.29	2.5” S9.5B*****		8” ABC	2.22
2.30 - 2.57	2.5” S9.5B*****		10” ABC	2.50
2.58 - 3.11	2.5” S9.5B	2.5” I19.0C	6” ABC	3.04
3.12 - 3.39	2.5” S9.5B	2.5” I19.0C	8” ABC	3.32
3.40 - 3.67	2.5” S9.5B	2.5” I19.0C	10” ABC	3.60
B, C, & D LEVEL DESIGNS (Use when 20 year ESALS are >0.3 Million)				
<2.23	3.0” S9.5X		6” ABC	2.16
2.24 - 2.51	3.0” S9.5X		8” ABC	2.44
2.52 – 2.79	3.0” S9.5X		10” ABC	2.72
2.80 - 3.33	3.0” S9.5X	2.5” I19.0C	6” ABC	3.26
3.34 - 3.61	3.0” S9.5X	2.5” I19.0C	8” ABC	3.54
3.62 - 3.89	3.0” S9.5X	2.5” I19.0C	10” ABC	3.82

*** Prime coat required**

Curb and Gutter Designs:

(Determine if load level is B, C, or D by using the 20 year ESALS - Page 7)

Table B-1 Recommended Pavement Design - (Full Depth)				
Required Structural Number	**Surface**	**Inter.**	**Base**	**Structural Number Provided**
<4.35	3.0” S9.5X	4.0” I19.0C	4.0” B25.0C	4.28
4.36 - 4.50	3.0” S9.5X	4.0” I19.0C	4.5” B25.0C	4.43

(Determine if load level is B, C, or D by using the 20 year ESALS - Page 7)

Table B-2 Recommended Pavement Design (ABC)				
Required Structural Number	**Surface**	**Inter.**	**Base**	**Structural Number Provided**
<3.99	3.0” S9.5X	4.0” I19.0C	6” ABC	3.92
4.00 - 4.27	3.0” S9.5X	4.0” I19.0C	8” ABC	4.20
4.28 - 4.55	3.0” S9.5X	4.0” I19.0C	10” ABC	4.48

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 presented before the Pavement Review Committee 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 (typically one core for every five FWD test locations).

2. Temperature and FWD deflection data at least every 500 ft. in outside wheel path of outside lane to include all core locations. If project is less than one mile in length, deflections are to be taken every 200 ft.

3. Dynamic Cone Penetrometer (DCP) evaluations to a minimum depth of 24 in. (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 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)

D = total depth of pavement structure (in.)
(total pavement depth above subgrade)
Ep = effective modulus of pavement layer (psi)
(from temperature corrected deflection data)

Overlay SN = Required SN - Effective SN

Design 3 - Effective Modulus

The number of 18 kip 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*109/Wt18)/3.34)) (ABC)
or, Dt = 10^((log(5.6*1011/Wt18)/4.6)) (Full depth asphalt)

Dt = target FWD deflection (mils) (desired deflection limit),
W_{t18} = number of 18 kip 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 = $2*1000*P*(1-\mu^2)/(\tilde{a}* r *D0)$

P = FWD load (lbs)
μ = Poisson's ratio
r = radius of loaded area (in.)
ã = 3.14159...
D0 = Temperature corrected deflection under load plate (mils)

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 ÷ 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)

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)
D = overlay thickness (in.)
Modulus = overall pavement modulus (one layer modulus representing entire pavement structure and subgrade) (psi)

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 be constructed utilizing a Permeable Asphalt Drainage Layer (PADC) and an asphalt separating layer under the concrete layer in order to provide uniform support and positive drainage, when Average Daily Truck Traffic (ADTT) > 2000 trucks per day.

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 40,000 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’ intervals for the outside shoulders and 500’ for median shoulders. 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 red reflective pavement markers at the pavement edge on asphalt surfaces.

UNIT COSTS

The unit costs for pavement pay items are obtained from Contract Standards and Development Unit. The request for unit costs should include the project location and description and a complete listing of pay items and corresponding total quantities. A list of the required unit cost for all pavement types are listed below:

CY SHOULDER BORROW
GAL ASPHALT CURING SEAL
GAL PRIME COAT (ON ABC)
LAB AND SURFACE TESTING COST FOR RIGID PAVEMENTS
LF 4" SHOULDER DRAIN PIPE
LF SAW AND SEAL CONCRETE JOINTS
LF SHOULDER DRAIN
SY CEMENT TREATED SOIL
SY X.X IN. DEEP ASPHALT FULL DEPTH REPAIR
SY APPLICATION OF UTBWC
SY ASPHALT SURFACE TREATMENT - MT COAT #5 STN
SY CONCRETE SHOULDARD ADJ. TO PAVE DEPTH
SY DIAMOND GRIDDING
SY FOG SEAL PAVED SHOULDERS
SY LIME TREATED SOIL
SY MILL ASPHALT PAVEMENT X.X IN DEPTH
SY NONWOVEN GEOTEXTILE INTERLAYER
SY X.X DEEP CONCRETE PATCH
SY X.X IN. PORT CEM CONC PAVE W/ DOW. THRU LNS
TON AGGREGATE BASE COURSE
TON ASPHALT CEMENT FOR PLANT MIX (EACH TYPE SEPERATELTY)
TON ASPHALT CONCRETE BASE COUR TYPE B25.0C
TON ASPHALT CONCRETE INTERM COUR TYPE I19.0C
TON ASPHALT CONCRETE SURF COUR TYPE S9.5X
TON ASPHALT CONCRETE TYPE PADC
TON LIME FOR LIME TREAT SOIL
TON PADC
TON PLANT MIX CEMENT TREATED BASE COURSE
TON PORTAND CEMENT FOR PLANT MIX CTABC
TON PORTLAND CEMEMENT FOR SOIL CEMENT BASE
TON STABILIZER AGGREGATE
TON UBWC BINDER GRADE PG 70-28
TON UBWC MIX

APPROVED LIFE CYCLE COST ANALYSIS

- LCCA will be done for pavement projects greater than 1 mile in length for which initial traffic is greater than 10,000 vehicles per day (vpd) and which are either reconstruction or are located on new location. Expansion of use of LCCA to rehabilitation projects will require additional outreach to industry to determine future treatments and their timing.
- A Present Worth Analysis with a 45 year analysis period is used. The discount rate shall be the 30-year Real Treasury Interest Rate as provided in the Office of Management and Budget (OMB) Circular A-94 Appendix C. The average rate will be updated after the beginning of year OMB adjustment and that rate will be used until the next year's "beginning of year adjustment".
- A 30-year design life will be used for the initial design for both flexible and rigid pavements. Subsequent treatments are identified in the tables below.
- Flexible pavement alternates will include full depth asphalt, asphalt over dense graded aggregate (ABC) and asphalt over cement treated aggregate base course (CTABC).
- For Average Daily Truck Traffic (ADTT) > 2,000 vehicles per day, concrete pavement alternatives will include jointed concrete pavement with tied concrete shoulders and jointed concrete pavement with widened (13') outside lane with flexible shoulders. High truck volume concrete pavements will include a 3 inch drainage layer and a 1.25" asphalt separator layer.
- For pavements with less than 2,000 trucks per day, the concrete pavement will be placed on 6" of dense graded ABC. These will use either a 12 foot lane width and asphalt shoulders or a 13 foot lane with a reduced width asphalt shoulder, depending on cost.
- Subgrade Stabilization will be required when recommended by the Geotechnical Engineering Unit.
- Where the life of a treatment extends beyond the end of the analysis period, a salvage (remaining life) value equal to the unused fraction of the expected life is subtracted at the end of the analysis period. For example, for flexible pavement, additional thickness is added at year 34 to provide an additional 20 years of life. At the end of the analysis period, this treatment will have 45% (9/20) of the value of the year 34 treatment as a salvage value.
- User costs will be calculated using FHWA software, Real Cost, to include user delay costs and the increase in vehicle operating costs associated with work zone delays. User costs will be discounted and a Present Worth Analysis will be conducted. User costs will be separate from the agency costs and user costs for alternate pavement designs that are within 20% of each other will be considered equal. Calculation of user cost is new for NCDOT, will require additional training and will be implemented by June 30, 2015.
- Agency cost LCCA will be considered equal between alternatives if the LCCA's are within 10 percent.
- Selection criteria:
  Regardless of the difference in LCCs, urban constructability will also be considered and will include the impacts of utilities, curb and gutter, sidewalks, maintenance of traffic, etc.

  1. If the calculated LCCs are within 10%, alternate bids may be considered. We will consider adjacent pavement types with a goal of maintenance consistency for 3-mile segments. Impacts to the public and to businesses will also be considered. Issues still remain with regard to FHWA Technical Guidance on Alternate Bidding and NCDOT will not resume alternate bids until FHWA concurs with our process.
  2. If the difference in the LCCs is between 10% and 15%, we will consider division preference in concurrence with the Chief Engineer. User costs will be considered if the user costs are different by more than 20%. Note that the implementation date for user costs is June 30, 2015.
  3. If the difference in the LCCs is greater than 15%, we will use the lowest LCC alternative unless construction issues preclude its use. Issues will be documented in the project design file.

Costs included in Life Cycle Cost Analysis

Time to Treatment	Flexible Pavements	Rigid Pavement
0	Initial construction with 30 year design	Initial construction with 30 year design.
12 years	Cost to mill and replace 1.5" of surface course and to fog seal shoulders.	
17 years		Cost to saw and reseal joints and patch 1% of travel lanes. Fog seal asphalt shoulders with 1% patching if asphalt shoulders are present.
23 years	Cost to mill and replace 1.5" of surface course, including shoulders.	
30 years		1% patching. Overlay with ultrathin bonded wearing course (10 year life); 1% patching with diamond grinding will be considered on concrete with dowels and 15 ft. joint spacing.
34 years	Cost to mill 3" and add structure to achieve 20 more years of life. For high volume, replace milling with intermediate course and overlay with 2 lifts of surface. For lower volume, replace milling with intermediate course and overlay with 1 lift of surface course. For curb and gutter, 5% full depth patching, mill 3" and replace with surface course.	
40 years		Cost for 5.5" Asphalt Overlay with life of 20 years.
45 years	Salvage value of 45% of year 34 treatment.	Salvage value of 75% of year 40 treatment.

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. LCCA
2. Traffic,
3. Soils characteristics,
4. Weather,
5. Construction consideration,
6. Recycling,
7. Cost comparison,
8. Pavement performance,
9. Adjacent existing pavements,
10. Conservation of materials and energy,
11. Availability of local materials or contractor capabilities,
12. Traffic safety,
13. Incorporation of experimental features,
14. Stimulation of competition, and
15. 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 by the Project Design Engineer. These requests will normally be more than one year from the anticipated letting date. 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 white sheet printout that will include all design input information, a required SN, and a recommended pavement design. Designs for Y-lines, ramps, and shoulders may be summarized on the white sheet.

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. LCCA will be done for pavement projects greater than 1 mile in length for which initial traffic is greater than 10,000 vehicles per day (vpd) and which are either reconstruction or are located on new location. Quantity estimates are to be prepared and submitted to the Estimating Management in the Technical Services Unit for unit cost estimates. From these cost estimates, a per liner foot cost for the predominant typical section is to be determined. Typical cost comparisons are to be made between full depth asphalt, aggregate bases, and cement treated bases. For Average Daily Truck Traffic (ADTT) > 2000 trucks per day, concrete pavement alternatives will be used including jointed concrete pavement with tied concrete shoulders and jointed concrete pavement with widened (13') outside lane with flexible shoulders.

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 10 %. 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. The LCCA will be verified 6 months before the let date to make any updates with the unit costs. This is to insure that the alternate designs selection criteria has not been affected by any updated unit cost.

PAVEMENT REVIEW COMMITTEE

The Pavement Review Committee meets on the last Thursday of each month at 2:00 P.M. Target review dates at least 12 to 15 months prior to schedule letting (turn in date for consultants). Members of the review committee consist of representatives from the following units:

Construction
FHWA
Geotechnical
Materials and Test Pavement Section
STIP
Roadway Design
Traffic Management Unit/Work Zone Traffic Control

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

EXECTIVE REVIEW COMMITTEE

For projects where the pavement type selection is difficult, unclear, or potentially controversial, the pavement type selection made by the Pavement Review Committee will be reviewed by the Pavement Executive Committee, consisting of the Chief Engineer, the Deputy Chief Engineer, and the Division Engineer from the Division in which the project is located.

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.

Roadway Design Paved Shoulder Policy

ROADWAY DESIGN MANUAL PART 1
FIGURE 1 1 - 4 0
F - 1

	NCDOT PAVED SHOULDER POLICY
INTERSTATE AND FREEWAYS 6 OR MORE LANES	10' WIDE PAVED OUTSIDE SHOULDERS & 10' WIDE PAVED MEDIAN SHOULDERS (FULL DEPTH OR AS DIRECTED BY THE PAVEMENT MANAGEMENT UNIT.)
INTERSTATE 4 LANES	10' WIDE PAVED OUTSIDE SHOULDERS (FULL DEPTH OR AS DIRECTED BY THE PAVEMENT MANAGEMENT UNIT.) AND 4' WIDE FULL DEPTH PAVED MEDIAN SHOULDERS (REMAINING WIDTH TO BE TURF.)
FREEWAYS (DES YR. ADT ≥ 40000)	10' WIDE PAVED OUTSIDE SHOULDERS (FULL DEPTH OR AS DIRECTED BY THE PAVEMENT MANAGEMENT UNIT) AND 4' WIDE FULL DEPTH PAVED MEDIAN SHOULDERS (REMAINING WIDTH TO BE TURF.)
(DES YR. ADT < 40000) (DES YR. ADT ≥ 15000)	10' WIDE PAVED OUTSIDE SHOULDERS (4' OF WIDTH TO BE FULL DEPTH, REMAINING PAVED WIDTH TO BE SURFACE COURSE ON ABC, OR AS DIRECTED BY THE PAVEMENT MANAGEMENT UNIT.) 4' WIDE FULL DEPTH PAVED MEDIAN SHOULDERS (REMAINING WIDTH TO BE TURF.)
(DES YR. ADT < 15000)	4' WIDE OUTSIDE AND 4' WIDE MEDIAN FULL DEPTH PAVED SHOULDERS. (REMAINING SHOULDER WIDTH TO BE TURF)
DIVIDED: ARTERIALS, COLLECTORS 6 OR MORE LANES	10' WIDE PAVED OUTSIDE SHOULDERS (4' OF WIDTH TO BE FULL DEPTH, REMAINING PAVED WIDTH TO BE SURFACE COURSE ON ABC OR AS DIRECTED BY THE PAVEMENT MANAGEMENT UNIT.) 4' WIDE FULL DEPTH MEDIAN SHOULDER. SEE NOTE 7.
DIVIDED: ARTERIALS, COLLECTORS 4 LANES (DES. YR. ADT ≥ 40000)	10' WIDE PAVED OUTSIDE SHOULDERS (4' OF WIDTH TO BE FULL DEPTH, REMAINING PAVED WIDTH TO BE SURFACE COURSE ON ABC OR AS DIRECTED BY PAVEMENT MANAGEMENT.) 4' WIDE FULL DEPTH PAVED MEDIAN SHOULDERS (REMAINING MEDIAN SHOULDER WIDTH TO BE TURF).
(DES. YR. ADT < 40000)	4' WIDE OUTSIDE & 2' WIDE MEDIAN FULL DEPTH PAVED SHOULDERS. (REMAINING SHOULDER WIDTH TO BE TURF)
MULTILANE UNDIVIDED: 4 OR MORE LANES (DES. YR. ADT ≥ 40000)	10' WIDE PAVED SHOULDERS (4' OF WIDTH TO BE FULL DEPTH, REMAINING PAVED WIDTH TO BE SURFACE COURSE ON ABC, OR AS DIRECTED BY THE PAVEMENT MANAGEMENT UNIT).
(DES. YR. ADT < 40000)	4' WIDE FULL DEPTH PAVED SHOULDERS. (REMAINING SHOULDER WIDTH TO BE TURF).
TWO LANE – TWO WAY : (DES. YR. ADT ≥ 8000)	4' WIDE FULL DEPTH PAVED SHOULDERS. (REMAINING SHOULDER WIDTH TO BE TURF).
(DES. YR. ADT ≥ 4000)	2' WIDE FULL DEPTH PAVED SHOULDERS. (REMAINING SHOULDER WIDTH TO BE TURF).
(DES. YR. ADT < 4000)	FULL SHOULDER TO BE TURF. NOTE: 4' PAVED SHOULDER MAY BE CONSIDERED FOR BIKE ROUTES.
RAMPS LEFT SHOULDERS	4' WIDE FULL DEPTH PAVED SHOULDER (REMAINING SHOULDER WIDTH TO BE TURF).
RIGHT SHOULDERS	4' WIDE FULL DEPTH PAVED SHOULDER (REMAINING SHOULDER WIDTH TO BE TURF). SEE NOTE 5

NOTES:
1. PAVED SHOULDER WIDTH SHOULD NOT EXCEED USABLE WIDTHS AS DEFINED IN ROADWAY DESIGN MANUAL EXCEPT AT GUARDRAIL LOCATIONS AS SHOWN IN STD. 862.01.
2. A 12' WIDE PAVED OUTSIDE SHOULDER SHOULD BE CONSIDERED FOR INTERSTATES AND FREEWAYS HAVING TRUCK TRAFFIC WHICH EXCEEDS 250 DDHV. A 12' WIDE PAVED MEDIAN SHOULDER SHOULD BE CONSIDERED FOR THOSE FAC WHICH HAVE SIX OR MORE LANES AND TRUCK TRAFFIC EXCEEDING 250 DDHV.
3. FREEWAYS THAT WARRANT 12' PAVED SHOULDERS DUE TO HEAVY TRUCK TRAFFIC AND THE DESIGN YEAR ADT ≥ 40,000 WILL BE DESIGNED WITH 12' FULL DEPTH PAVED SHOULDERS. 12' WIDE MEDIAN PAVED SHOULDERS WILL CONSIST OF 4' WIDTH FULL DEPTH WITH THE REMAINING PAVED WIDTH BEING SURFACE COURSE ON ABC OR AS DIRECTED BY THE PAVEMENT MANAGEMENT UNIT.
4. RUMBLE STRIPS, PAVEMENT TEXTURING OR OTHER APPROVED METHODS FOR DELINEATING MAINLINE PAVEMENT SURFACES FROM SHOULDER PAVEMENT SURFACES SHOULD BE USED ON RURAL INTERSTATE AND FREEWAY SHOULDER SURFACES.
5. THE PAVEMENT MANAGEMENT UNIT SHALL DETERMINE THE PAVED SHOULDER DESIGN ON A PROJECT BY PROJECT BASIS.
6. THE FULL USABLE SHOULDER WIDTH OF INDIVIDUAL RAMPS MAY BE TAPERED OR DECREASED SHOULDER USAGE IS APPARENT OR EXPECTED BASED ON TRAFFIC ANALYSIS. THE TAPER SHALL BE FULL DEPTH PAVEMENT AND THE REMAINING PAVED WIDTH SHALL BE SURFACE COURSE ON ABC OR AS DIRECTED BY PAVEMENT MANAGEMENT UNIT. A RECOMMENDATION TO PAVE THE FULL USABLE WIDTH CAN BE MADE AT THE PROJECT FIELD INSPECTION AND IS TO BE APPROVED BY THE STATE ROADWAY DESIGN ENGINEER.
7. THE FULL WIDTH OUTSIDE AUXILIARY LANE SHOULDERS SHALL BE PAVED IF THE AUXILIARY LANE CONNECTS INTERCHANGES OR IS LONGER THAN 2500 FEET. ON THE PAVED WIDTH, SHALL BE FULL DEPTH PAVEMENT AND THE REMAINING PAVED WIDTH SHALL BE SURFACE COURSE ON ABC, OR AS DIRECTED BY THE PAVEMENT MANAGEMENT UNIT.
8. CONSIDER 10' PAVED MEDIAN SHOULDERS FOR SPEEDS ≥ 55 MPH.

Quick Check List – Flexible Designs

- ☐ All input values used in the design equations are correct values.
- ☐ Your design has 2 layers of surface if possible
- ☐ Your design has an asphalt base, ABC, or CTABC layer
- ☐ All layers are within the allowable minimum and maximum layer depths
- ☐ The surface and intermediate layers all match the face of curb and gutter, if present on the project.
- ☐ Correct loading levels are chosen for each pavement layer.
- ☐ Minimum Structure Depths are meet for type of roadway.
- ☐ Structure number of provided design meets the required structure number.
- ☐ Thin-Depth paved shoulder design is provided if present on project.
- ☐ Y-Line designs are provided if present on project.
- ☐ Detour designs are provided if present on project.
- ☐ Shoulder drains are provided if required on project.

List of Revisions

Revision Date	Description
2-2-2018	Updated to reflect the mix consolidation changes in the 2018 QMS manual.