9-A-4

Sample Problems and Completed Forms

A4.1 New or Reconstructed Pavement Design Sample Problem and Completed Form

Approximately 6,000 feet of Broadway Street (Route 107) is being reconstructed in Revere. The area has seen commercial and industry development and an increase in traffic volumes. Broadway is a two-lane urban facility. The following data is given.

- 2005 ADT = 21,640
- 2025 ADT = 22,480
- T (ADT) = 5%

Problem:
Determine the pavement structural design for a 20-year period.

Solution:

Data Sheet 1
Lines (a) to (g) on Data Sheet 1 are completed as instructed. Exhibit 9-2 is used to select the ESAL applications per 1000 trucks and combinations. The urban roads value of 800 is used and entered on Line (g). Therefore, Line (h) is 440.

DBR Determination
Line (h) (T_{18}) exceeds 120. Therefore, according to Exhibit 9-4, PDE must determine the DBR for the subgrade.

Data Sheet 2
- **Step 1:** The design lane equivalent for a two-lane undivided highway is 1.00 x Line (h) which, in this case, is 440.
- **Step 2:** PDE determines that the subgrade DBR is 9.
- **Step 3:** Using Exhibit 9-7, The subgrade SSV = 4.2; The subbase SSV = 7.8.
- **Step 4:** Using Exhibit 9-8, the required SN above the subbase is 2.6; above the subgrade it is 4.15.
- **Step 5:** Increasing these values by 15% yields SN design values of 2.99 and 4.77.

Data Sheet 3
Use the trial-and-error procedure to determine the most economical design which satisfies the SN requirements for the subbase and subgrade. The following design is selected:

1 ¾-inches of HMA surface course standard 1 ¾-inches of HMA intermediate course dense
4 ½-inches HMA base course standard
4 inches of dense graded crushed stone over
10 inches of gravel sub-base

A completed summary sheet and completed data sheets follow.

COMMONWEALTH OF MASSACHUSETTS
MassHighway

PAVEMENT DESIGN
NEW AND RECONSTRUCTED PAVEMENTS

City/Town	Revere		
Route No.	Broadway St. (Rte.107)	**Highway System**	Urban Collector
From Station	54+00I	**To Station**	114+00I
No. of Lanes	2 Travel Lanes		
Date of Pavement Design:	2/24/05	**Pavement Design By:**	Pavement Designer

RECOMMENDED PAVEMENT STRUCTURE

Surface Course:	1 ¾-inch HMA Surface Course over
Intermediate Course:	1 ¾-inch HMA Intermediate Course over
Base Course:	4 ½-inch HMA Base Course placed in one layer over
Sub-base:	4-inch Dense Graded Crushed Stone Sub-base over 10-inch gravel sub-base
Sub-grade	Undisturbed existing sub-grade

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

City/Town	Revere		**Route No.**	107	
From Station	54+00		**To Station**	114+00	
No. of Lanes	2	**Highway System**	Urban Collector	**Date**	2/2/4/05
Current ADT	2005				

Terminal Serviceability Index (T.S.I) = 2.5

(a) Day of Opening A.D.T. (Date 2005)*	21,640
(b) Future A.D.T. (Date (a) + 20 years)**	22,480
(c) Mean A.D.T. = [(a) + (b)] / 2	22,060
(d) Mean A.D.T. in One Direction = (c) / 2	11,030
(e) A.D.T. Truck Percentage ("T" A.D.T.)	5
(f) Mean Truck A.D.T. In One Direction (d) x (e)	550
(g) ESAL Application per 1000 Trucks and Combinations Exhibit 9-2	800
(h) ESALs Per Day in One Direction	440
(f) X (g) / 1000 (T_{18})	

Comments:

*Anticipated traffic when facility is opened to travel.
**Under certain conditions this may change to a larger or shorter period.

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 2: DETERMINATION OF STRUCTURAL MUMBER (SN)

Design Lane ESAL Applications (T_{18})

For 2-Lane Undivided Highway

Design Lane T_{18} = 1.00 x Total T_{18}* = 1.00 x 440 = 440

For 4 (Total Lanes) Lane Divided Highway

Design Lane T_{18} = 0.90 x Total T_{18}* = 0.90 x ..... = _____

Design 6 or More (Total Lanes) Divided Highway

Design Lane T_{18} = 0.80 x Total T_{18}* = 0.80 x .....= _____

Design DBR + SSV Exhibits 9-4, 9-5 & 9-7, Sections 9.6 Exhibit 9-7

Subbase	Gravel	DBR =	40	SSV =	7.8
Subgrade		DBR =	9	SSV =	4.2

Design Structural Number (SN)

Apply Design SSV and Design Lane T_{18} from above to Design Nomograph (Exhibit 9-8)

	From Exhibit 9-8	+15%
Above Subbase .....=	2.6	2.99
Above Sugrade ..... =	4.15	4.77

*From Line (h) of Data Sheet 1.

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 3: PAVEMENT STRUCTURAL NUMBER (SN)

$$SN = D_1a_1 + D_2a_2 + D_3a_3 + D_4a_4 + D_5a_5$$

Surface Course				
Material:	1 ¾" HMA	D_1a_1=	1.75 x .44 =	0.77
Intermediate Course				
Material:	1 ¾" HMA	D_2a_2=	1.75 x .44 =	0.77
Base Course				
Material:	4½" HMA	D_3a_3=	4.5 x .34 =	1.53
	Total SN Above Subbase		=	3.07 > 2.99
Subbase (Foundation)				
Material:	4" crushed stone	D_4a_4=	4 x .14 =	0.56
	10" gravel	D_5a_5=	10 x .11 =	1.10
	Total SN Above Subbase		=	4.73 ~4.77

Where: D_1 = Surface Course Thickness, inches

D_2 = Intermediate Course Thickness, inches

D_3 = Base Course Thickness, inches

D_4 = Sub-base Thickness, inches

D_5 = Subbase Thickness, inches

a_1 = Coefficient of Relative Strength, Surface

a_2 = Coefficient of Relative Strength, Intermediate

a_3 = Coefficient of Relative Strength, Base

a_4 = Coefficient of Relative Strength, Sub-base

a_5 = Coefficient of Relative Strength, Subbase

Comments:

Overlay Design
Sample Problem and Completed Form

Approximately 2460 feet of Route 3 in Hingham is being resurfaced overlayed. Route 3 is a four-lane urban freeway facility. The existing pavement exhibits some moderate severity cracking , raveling of longitudinal joints and patch repairs. The last resurfacing of this road was in 1989. The following data is given.

- 2005 ADT = 52,000
- 2025 ADT = 66,000
- T (ADT) = 6%

Existing Pavement:
- 6 inch hot mix asphalt
- 4½ inch penetrated crushed stone base
- 12 inch gravel subbase
- 2 inch proposed milling

Problem:
Determine the depth of hot mix asphalt overlay for a 20-year design period.

Solution:

Data Sheet 1
- **Line (a)- Line (f):** Completed as instructed
- **Line (g):** Exhibit 9-2 yields a value of 1000
- **Line (h):** This calculation yields a T_{18} = 1768
- **Line (i):** For a four-lane facility, the design lane ESAL is (0.9 x T_{18}), or 1593
- **Line (j):** The PDE provides a subgrade DBR of 11, which yields SSV = 4.5
- **Line (k):** Exhibit 9-8 yields an SN 3.67 above the subgrade
- **Line (l):** Increasing by 15% yields a design SN of 4.22

Data Sheet 2
- **Line (a):** The subgrade SSV = 4.5 is entered.
- **Line (b):** Exhibit 9-12 is used to select the layer coefficients for the existing pavement. The existing pavement is in generally good condition. Therefore, a reduction factor of 0.9 is selected from Exhibit 9-13. The calculations are shown on the completed data sheet
- **Line (c):** The actual SN above each pavement layer is entered s shown on the completed data sheet

Data Sheet 3
- **Line (a):** Exhibit 9-8 is used to determine the required SN above each layer of the existing pavement. These are increased by 15% as shown.
- **Line (b):** The SN deficiency for each layer of the existing pavement is shown on the completed data sheet
- **Line (c):** The largest SN deficiency is 1.75 for the subgrade. This is used to determine that a 4 inch overlay is needed to provide acceptable pavement performance over the 20-year period.

A completed summary sheet and completed data sheets follow.

COMMONWEALTH OF MASSACHUSETTS
MassHighway

PAVEMENT RESURFACING OVERLAY DESIGN

City/Town	Hingham		
Route No.	3	**Highway System**	Freeway
From Station	85+00	**To Station**	109+60
No. of Lanes	4		
Date Pavement Designed	Date	**Pavement Designed By:**	Pavement Designer

EXISTING PAVEMENT STRUCTURE

Depth	Existing HMA Pavement Course
1 ½"	HMA Surface Course
	HMA Intermediate Course
4 ½"	HMA Base Course
4½"	Dense Graded or Penetrated Crushed Stone
	Sub-base
12"	Sub-grade

PROPOSED MILLING

2" PROPOSED MILLING DEPTH
4" EXISTING HMA DEPTH AFTER MILLING

RECOMMENDED OVERLAY THICKNESS TO BE PLACED OVER MILLED SURFACE

2" HMA SURFACE COURSE
2" HMA INTERMEDIATE COURSE

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

Terminal Serviceability Index Nomograph = 2.5

(a) Current A.D.T. (Date 2005)	52,000
(b) Future A.D.T. (Date 2025)	66,000
(c) Mean A.D.T. = $\frac{[(a) + (b)]}{2}$	33,000
(d) Mean A.D.T. in One Direction = $\frac{(c)}{2}$	29,500
(e) A.D.T. Truck Percentage	6%
(f) Mean Truck A.D.T. In One Direction (d) x (e)	1768
(g) ESALs per 1000 Trucks and Combinations Exhibit 9-2	1000
(h) Number of ESALs Per Day in One Direction $\frac{(f) \times (g)}{1000}$ (T_{18})	1768
(i) ESALs on Design Lane: (h) x 1.00 for 2 lanes; (h) x 0.90 for 4 lanes; (h) x 0.80 for 6 or more lanes	1593
(j) Sub-grade Design Bearing Ratio and Soil Support Value	DBR = 11:SSV= 4.5
(k)* Structural Number (SN) Required above this Subgrade	3.7
(l)* Increase SN by 15% for Design SN	4.26

*These values are developed on Data Sheet #3.

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 2: ACTUAL SN OF THE EXISTING PAVEMENT STRUCTURE

a) Soil Support Values of Existing Granular Base and/or Sub-base

Dense Graded or Penetrated Crushed Stone Sub-base	= 9.0
Gravel Base and/or Subbase	= 6.6
Subgrade	= 4.5

(b) Actual Structural Number (SN) of Each Layer of Existing Pavement

(1) Depth		(2) Coefficient Exhibit 9-10	(3) RF Exhibit 9-11	SN ((1)X(2)X(3)
4"	Hot Mix Asphalt	0.44	0.9	1.6
4½"	DGCS or Penetrated Crushed Stone Sub-base Base	0.24	0.9	0.97
12"	Gravel Base and/or Sub-base	0.11	0.9	1.19
			Total SN =	3.7

(c) Actual Structural Number (SN) Above Each Layer of Existing Pavement

Above Top Of:	SN* HMA	SN* Pentrat. Stone	SN* Sand-Bd. Stone	SN* Gravel	Total SN*
DGCS or Penetrated Crushed Stone Sub-base Base	1.6				1.6
Gravel Base and/or Sub-base	1.6	1.0			2.6
Sub-grade	1.6	1.0		1.2	3.7

*From Table (b) Above
**Accumulated SN Values from layers Above
Gravel Base (for low volume design < 2000 adt)

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 3: DETERMINATION OF OVERLAY THICKNESS

(a) Required Structural Number (SN) Above Each Layer of Existing Pavement

	SN	+15%
Above Top of Penetrated Crushed Stone Base =	2.62	3.01
Above Top of Gravel Base and/or Sub-base =	3.67	4.22
Above Top of Subgrade =	4.78	5.50

(b) SN Deficiency to be Corrected With an Overlay

Above Top Of:	Required SN*	Actual SN**	SN Difference
Penetrated Crushed Stone Base	3.01	1.58	1.43
Gravel Base and/or Sub-base	4.22	2.56	1.66
Sub-grade	5.50	3.74	1.75

*From (a) Data Sheet #3
**From (c) Data Sheet #2

(c) Thickness of Hot Mix Asphalt Overlay

$$\text{Depth} = \frac{\text{Largest SN Difference}}{0.44} = \frac{1.75}{0.44} = 3.98 \text{ inches} \quad \text{use } 4 \text{ inches}$$