Ministry of Transportation and Infrastructure

PAVEMENT STRUCTURE

DESIGN GUIDELINES

Technical Circular T- 01/15

(Replaces Technical Circular T-01/04)

Final Update: Jan. 26, 2015

Geotechnical, Materials and Pavement Engineering

TABLE OF CONTENTS

1.0 PURPOSE

This technical circular identifies the recommended pavement structure design process to determine various structure thicknesses for new construction and rehabilitation of roads and highways under the jurisdiction of the Ministry of Transportation and Infrastructure in the Province of British Columbia.

This guideline provides both typical pavement structure types and pavement design criteria to be considered through the design process completed by a Ministry, Consultant, or Contractor’s Engineer.

Pavement structure is typically made up of the following three layers:

1. Asphalt Pavement (AP);
2. Crushed Base Course (CBC); and
3. Select Granular Sub-Base (SGSB).

2.0 BACKGROUND

On numbered highways, the Ministry’s standard practice has been the use of relatively thin, flexible pavement layers consisting of 75 to 150 mm of dense graded Asphalt Pavement placed on CBC and SGSB layers.

This approach results in associated savings of construction cost and allows for future applications of cost effective rehabilitation strategies while achieving design requirements and a smooth pavement surface.

3.0 PAVEMENT DESIGN PROCESS

For existing pavement structures, a pavement condition evaluation shall use the Ministry’s Pavement Surface Condition Rating (PSCR) manual to determine existing pavement distress conditions and identify structural deficiencies of the pavement structure.

The Pavement Design Process is to:

1. Review existing information – existing pavement structure, historical strength test results, drainage characteristics, pavement history, foundation conditions, Roadway Pavement Management System data, etc.
2. Field evaluations – Collect/Check/Confirm design parameters and assumptions through field tests, and sampling, and collection of other data (traffic, strength, and distresses) needed for the design process;
3. Apply design method and parameters – using design inputs and assumptions for selected design method,
4. Finalize design– Provide a pavement design with analyzed data and rational assumptions.

   Rehabilitation options with life cycle costing shall be considered in the pavement design process.

   The pavement design is to be summarized in a report (described in Section 3.10).

3.1 Typical Pavement Structure Type A, B, C, and D

The designer is to

1. determine the applicable pavement structure type for the project and;
2. check that each layer thickness is sufficient for structural strength and other site specific issues.

The standard pavement structure type may be revised to meet project specific requirements.

Alternative pavement structure designs are discussed in Section 3.7.

Four typical pavement structures used by MoT are Type A, B, C, and D shown in Table 1.

Pavement Structure Type is determined by considering the traffic loading over a 20 year design life, subgrade type, drainage, local climate and other related factors.

Table 1: Pavement Structure Type

Pavement Structure Type	Roadway Designation	20 yr. Design ESAL Criteria	Typical Asphalt Concrete Pavement Thickness
A	High Volume Roads, Truck Lanes, Specialty Locations	> 20,000,000	≥150 mm
B	Medium to High Volume Roads	100,000 to 20,000,000	75 to 150 mm
C	Low Volume & Subdivision Roads	< 100,000	50 to 75 mm
D	Low Volume Sealcoat or Gravel Road	< 100,000	Graded Aggregate Sealcoat Layer(s)

Cross sections of typical pavement structure types are shown in Appendix A with variations in layer thicknesses depending on design EASL's and foundation conditions.

Gravel roads may use a high fines surfacing aggregate (SS 202) for its running surface if no graded aggregate sealcoat surface is used.

These guidelines are consistent with the standard drawings in the BC Supplement to the TAC Geometric Design Guide (current edition).

3.2 Pavement Structure Design Methods

Acceptable Pavement Structure Design Methods are:

- AASHTO 1993 Guide for the Design of Pavement Structures.

  MoT specific input parameters are discussed in Section 3.5.

- AASHTO (2004) ME Pavement (Mechanistic Empirical Pavement Design Method Guide)

  A relatively new pavement design process based on engineering mechanics and validated with extensive road test performance data.

  This comprehensive, computer-based design program predicts multiple performance indicators (stresses, strain, and deflections) based on detailed measured input parameters

- In house pavement structure design program(s) used by the Consultant and accepted by the Ministry; or
- Other methods such as ELMOD (Dynatest ELMOD software is used for rehabilitation overlay design and is not to be used for design of new pavement construction), Shell method, etc.

3.3 Asphalt Pavement Layer

Typical asphalt surfaces are:

- Hot Mix, Warm Mix, Graded Aggregate Seal Coats, etc.

Sandwiched asphalt pavement layers must not be designed nor constructed to prevent future drainage problems of trapping water between the layers which can lead to accelerated structural damage of the asphalt pavement layer (heaving and reduced structural strengths).

When reducing the thickness of the asphalt layer pavement for economic reasons, consideration must be given to the net results of:

- A reduction in the expected pavement life (earlier rehabilitation), and
- An increase of pavement maintenance requirements.

The layer thickness selection method from AASHTO 1993 is determined as a minimum where the strain in the asphalt layer and the stress on each successive pavement layer and the subgrade are calculated to be within acceptable levels.

Increasing the thickness of gravel base (CBC) or sub-base (SGSB) components may sufficiently increase structural strength to offset reduced asphalt pavement thickness provided the base of the asphalt layer is less than 60 μ strain.

Asphalt binder grades used by the Ministry depend on the location, climatic and traffic loading.

Typical asphalt binders (though may vary for location and application) are:

- South Coast Region – 80/100A Pen (PG 64-22);
- Southern Interior Region – 120/150A Pen (PG 58-28); and
- Northern Interior Region – 150/200A Pen. (PG 58-28).

Specialty asphalt binders (such as PG Grade 70-22) may be considered for addressing rutting problems in heavier traffic loading locations.

Penetration grade asphalt cements are currently specified in Ministry contracts to ensure asphalt binder comes from Western Canada's high quality crude oil sources.

Allowable percentage of recycled asphalt pavement (RAP) usage varies depending is determined by the Regional Pavement Engineer on the numbered highway; and as specified in special provisions and using the current edition of the MoT Standard Specifications for Highway Construction SS 505 "Use of Reclaimed Asphalt Pavement in Asphalt Pavement Construction."

3.4 Granular Material Layers - Crush Base Course (CBC) and Select Granular Sub-Base (SGSB)

The required Crushed Base Course (CBC) and Select Granular Sub-Base (SGSB) thicknesses are to be determined by the pavement designer based on an acceptable design method outlined within this technical circular. Both of these materials must meet gradation and quality criteria as outlined in the current edition of the MoTI Standard Specifications for Highway Construction SS202 "Granular Surfacing, Base, and Sub-Bases".

3.4.1 Crushed Base Course (CBC)

All Ministry numbered highways and Ministry side roads with traffic volumes greater than 100,000 ESALs (Pavement Design types A and B) over the design period require a minimum thickness of 300mm of Crushed Base Course (CBC). Lower-volume side roads (Pavement Design Types C and D) require a minimum thickness of 225mm of Crushed Base Course (CBC).

The three Ministry-specific CBC products that fall under the category of CBC are:

- 25mm Well-Graded Base (25mm WGB),
- 25mm Intermediate-Graded Base (25mm IGB), and
- 25mm Open-Graded Base (25mm OGB).

In the respective order, the products become increasingly less sandy and more free-draining.

Both 25mm WGB and 25mm IGB are commonly used, while 25mm OGB is used in special circumstances where maximum drainage is required.

For two-product crushed base course structures, the lower layer is usually more free-draining and coarser (with a max nominal size of 50mm or 75mm).

3.4.2 Select Granular Sub-Base (SGSB)

Select Granular Sub-Base (SGSB) material typically consists of a 75mm-minus sand and/or gravel mixture that is either processed (screened and/or crushed) or drawn directly from a suitable aggregate source.

Dredged river sand shall not be considered for use as SGSB in the pavement structure due to the susceptibility for pavement rutting unless approved by the Ministry. Where dredged river sand may be contemplated, the angularity of the material and past performance of the dredged river sand source should be investigated and determined prior to any use of the material. In addition the sand needs to remain dry to avoid water piping the sand from the embankment.

SGSB may not be required in exceptional circumstances where the existing sub-grade material meets the structural design criteria and consists of a clean granular deposit that satisfy SGSB gradation and construction criteria outlined in the current edition of the MoT Standard Specifications for Highway Construction SS 202 “Granular Surfacing, Base and Sub-Bases.”

The depth of frost penetration and drainage must be considered in the design of SGSB thickness.

Minimum SGSB layer thicknesses are detailed in Table 2 and based on sub-grade type and design ESAL’s.

Table 2: Minimum SGSB thicknesses

Pavement Structure Type:	Subgrade Type:	Minimum SGSB thickness:
A, B,C, or D	Rock	150 mm
A or B (ESAL’s >100,000)	Soil	300 mm
C, or D (ESAL’s <100,000)	Soil Coarse Grained (Unified Soils Classification System - GW/GP/GM/GC/SW/SP/SM/SC)	150 mm
C, or D (ESAL’s <100,000)	Soil Fine Grained (Unified Soils Classification System - ML/CL/OL//MH/CH/OH)	300 mm

All leveling materials applied directly to blasted rock sub-grade shall be of SGSB quality.

3.5 Traffic Loading

The recommended method for determining the 20 year design Equivalent Single Axle Loads (ESAL's) is the Modified Asphalt Institute Method specified as follows.

ESAL CALCULATIONS MODIFIED ASPHALT INSTITUTE METHOD

ESAL = AADT * HVP * HVDF * NALV * TDY

where*:*

ESAL = Equivalent single axle loads per lane per year (for the base year)
AADT = Average annual daily traffic (all lanes & both directions)
HVP = Heavy vehicle percentage (divided by 100, to express as a decimal)
HVDF = Heavy vehicle factor (% (as a decimal) of heavy vehicles in design lane)**
NALV = Number of equivalent axle loads per vehicle (ESAL's per vehicle)
TDY = Traffic days per year

Note: ESAL's (base year) x 20 yr. traffic growth rate factor = 20 year Design ESAL's. Where there is no data, a growth rate factor of 2% is reasonable.

** see Kim, J.L.R. Titus-Glover, M.I. Darter, and R. Kumapley (1998), *Axel Load Distribution Characterization for Mechanistic Pavement Design,* Transportation Research Record No. 1629, Washington, DC

Ministry traffic data is typically available online from the Ministry Regional Traffic Engineer or from the Traffic Data Program website: www.th.gov.bc.ca/trafficData/index.html

The NALV requires explicit details about the traffic distribution including a breakdown on types of vehicles traveling the roadway. If this information is unavailable the following should be considered as the typical heavy vehicle breakdown:

- In areas where logging, and mining are the main industry, then assume that all heavy vehicles have an 8-axle B-train configuration at legal axle loading limits with a maximum Gross Combination Vehicle Weight of 63,500kg.
- Otherwise, assume that the heavy vehicles are a combination of 6-axle, 7-axle and 8-axle B-trains at legal axle loading limits.

In the calculation, ESAL's for various truck axle configurations are determined based on the Transportation Association of Canada (TAC) Vehicle Weights and Dimensions Study, illustrated in Figure 5 (ESAL's vs. Axle Group Load).

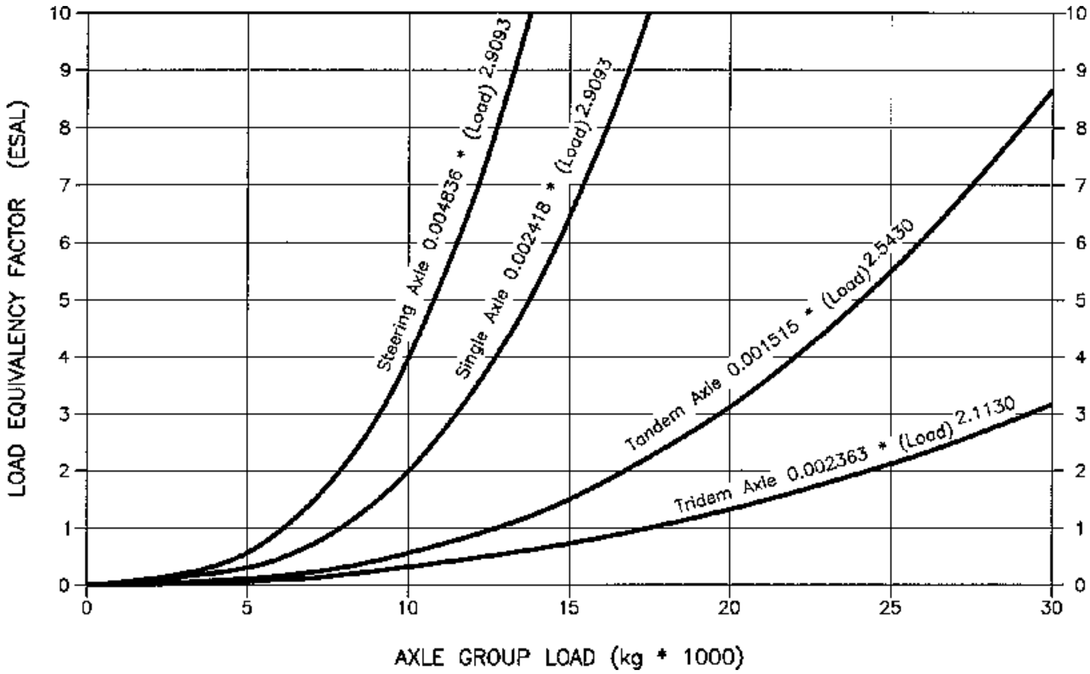


Figure 5: TAC VEHICLE WEIGHTS AND DIMENSIONS STUDY

3.6 AASHTO 1993 Pavement Design Parameters

In order to ensure a consistent design approach using the 1993 AASHTO method for new construction, the criteria shown in Table 3 shall apply.

Table 3: AASHTO 1993 Pavement Design Parameters

Analysis Period:	20 years
Reliability (R):	• High volume roads, R=90%; • Medium volume roads, R=85%; • Low volume & subdivision roads, R=75%
Standard Deviation (S_o):	S_o = 0.45
Pavement Serviceability Index (PSI):	• Initial Serviceability Index: (pi) = 4.2 • Terminal Serviceability Index: (pt) = 2.5

Materials Characterization:

Material Description	Resilient Modulus * (M_R) MPa (approx. psi)	Structural Layer Coefficient (ai)
Asphalt Pavement (AP)	2,750 (400,000)	0.40
Crush Base Course (CBC) (25 mm, 50 mm, & 75 mm)	200 (30,000)	0.14
Select Granular Sub-base (SGSB)	100 (15,000)	0.10

Drainage Coefficients (mi):

m_i	Crushed Base Course (CBC) Select Granular Sub-Base (SGSB) Description
1.15	Open Graded Crushed Base Course (CBC.) & Select Granular Sub-base (SGSB)
0.95	High Quality Crushed Base Course (CBC) & Select Granular Sub-base (S.G.S.S.) (i.e. <5% fines passing .075 mm sieve)
0.80	Poor quality Crushed Base Course (CBC) & Select Granular Sub-base (SGSB) (i.e. >5% fines passing .075 mm sieve)

*If field or laboratory resilient modulus values (M_r) are available, they may be used.

3.7 Alternative Pavement Structure Designs

Design options using life cycle costing are to be considered for determining the Pavement Structure Design Type and confirming layer thicknesses. One pavement design option shall be recommended for a Pavement Structure Design.

Where specific site conditions (ie granular quality and availability, etc.) and economic benefits warrant departure from these pavement design guidelines, Crushed Granular Equivalency (CGE) factors may be used as a guide for the development of alternative Pavement Structure Designs. CGE factors must be reported and justified.

The economic benefit of any alternative Pavement Structural design (minimum practical thicknesses are to be maintained) is to be determined on a project-specific basis. CGE factors for New Construction and Pavement Rehabilitation are provided in Table 4.

Table 4: Crushed Granular Equivalency (CGE) Factors for New Construction and Pavement Rehabilitation

PAVEMENT MATERIAL	CGE FACTOR
Bituminous Bound Layers	
Hot Mix Asphalt Pavement (AP) (uncracked)	2.0
Hot-Mix Asphalt Pavement (cracked)	1.5
Hot-in-Place Recycled Asphalt Pavement	1.7
Cold-in-Place Recycled Asphalt Pavement	1.5
B.C. Stabilizer (not generally used)	1.5
Open Graded Granular Base (Bituminous Bound)	1.5**
25mm Asphalt Base Course (ABC)	1.7
Recycled Asphalt Pavement in Granular Base Course (min 50% Aggregate) higher when the existing asphalt layer is pulverized into the grade	0.6* to 1.0
Portland Cement Bound Layers	
Portland Cement Concrete	3.0
Roller Compacted Concrete	2.5
Portland Cement Concrete (fair condition)	2.5
Portland Cement Concrete (poor condition)	2.0
Cement Treated Base	1.8
Open Graded Granular Base (Cement Bound)	1.6
Unbound Crushed Base Course Layers (25 mm, 50 mm & 75 mm)	
Well Graded Crushed Unbound Granular Base	1.0
Intermediate Graded Crushed Unbound Granular Base	1.1**
Open Graded Crushed Unbound Granular Base	1.2**
Old Granular Base	0.7
Old Granular Sub-base (Crushed)	0.7
Unbound Granular Sub-base Layers	
Well Graded Crushed Unbound Granular Sub-base	1.0
Intermediate Graded Crushed Unbound Granular Sub-base	1.1**
Open Graded Crushed Unbound Granular Sub-base	1.2**
Pit Run Granular Sub-base	0.7
Screened Granular Sub-base	0.7

***** Based on Ministry experience.

****** Based on Ministry experience and confined with a min. 75 mm of dense graded Asphalt Pavement.

Notes:

1. SURFACE TREATMENT:
For design, surface treatments (graded aggregate seal coats) are assumed to have no structural strength. Built-up layers of surface treatment (>75 mm thickness) could be assigned a CGE of 1.5 (un-cracked) and 1.1 (cracked).

2. WOVEN and NON-WOVEN GEOTEXTILES AND GEOGRIDS:
Non-Woven Geotextiles do not provide structural strength and are to be used only as separators. Woven Geotextile and Geogrids may provide structural equivalence if strength can be mobilized within the fabric or grid leading to a recalculation in frost heave resistance if the pavement structure is proposed to be reduced.

Alternative Pavement Designs Structures are to be presented to the Director of Geotechnical Engineering Branch for discussion and acceptance.

3.8 Types of Asphalt Road Surfaces

The Ministry has Hot Mix, Warm Mix (Additives and Processes), and Hot In Place Recycle asphalt road surfaces.

Often these surfaces are preserved with Graded Aggregate Seal (GAS) or micro-surface surface treatments.

Double-pass Graded Aggregate Seal (GAS) is commonly used by itself as an all-weather hard surface for lower-volume roads and high fines surfacing aggregate (HFSA) is often used for gravel surfacing of low volume roads.

3.9 Rehabilitation Strategies

Various rehabilitation strategies are utilized by the Ministry and each is a project-specific decision based on engineering, time lines and budget.

Typical Ministry rehabilitation strategies include, but are not limited to:

- Hot in Place Recycling with rejuvenator and with or without admix ,
- Mill and Fill, Mill and Overlay, or Mill/Fill/Overlay
- Pulverize/Pave,
- Overlay or Level Course/Overlay
- Seal Coat (Graded Aggregate Seal), Micro-surface etc.

3.10 Field Investigation and Laboratory Testing

The level and amount of Field Investigation and Laboratory Testing for new construction and rehabilitation is determined by the Ministry to collect and analyze the appropriate information for design and calculations.

Typical field investigations are carried out to determine subsurface foundation and ground water conditions; pavement layer thickness; and soil testing and asphalt concrete tests.

Investigations and testing are required to be thorough for the amount of information and confidence needed to make appropriate decisions.

There may be a need to carryout ground water monitoring.

Soil samples and other materials will follow standard soil testing practices to provide soil and granular reports on moisture content, particle size distribution, Atterberg Limits, Falling weight Deflectometer (DWF) etc.

Determination of the susceptibility of the sub-grade to frost heave is to follow Canadian Foundation Engineering Manual methodology and where this exists, the design be done to mitigate the effect.

Use of recycled materials- Asphalt Pavement are addressed in the current edition of the Standard Specifications SS505 “Use of reclaimed Asphalt pavement in Asphalt Pavement Construction” and Concrete in the “Guidelines for the Use of Recycled Materials in Base, Sub-base and Fill/embankment Roadway Construction” Technical Circular:

3.11 Pavement Structure Design Report

A pavement structure design report must be completed and submitted to the Ministry for each project. It will have a two to four page summary with the following design parameters identified. The process and methods must be documented in the report to show the assumptions and information used to determine the pavement structure design.

Design Traffic

Traffic information needs to be analyzed correctly to ensure ESAL's are calculated as close to expectations.

Design Life (years):	
AADT:	
Directional Distribution:	
Lane Distribution:	
% Trucks:	
Growth Factor:	
Traffic Days:	
Design ESAL's:	

Existing Pavement Layer Thicknesses (mm)

Surface treatment:	
Cold Mix Asphalt:	
Hot Mix Asphalt:	
Base (Granular A):	
Subbase (Granular B):	

Design Parameters

Initial Serviceability:	
Terminal Serviceability:	
Reliability:	
Standard deviation:	

Existing Materials Structural Layer Coefficients ("a" value) (sn/mm)

Surface Treatment:	
Cold Mix Asphalt:	
Hot Mix Asphalt:	
Base (Granular A):	
Subbase (Granular B):	

New Materials Structural Layer Coefficients ("a" value) (sn/mm)

Surface Treatment	
Cold Mix Asphalt	
Hot Mix Asphalt	
Base (Granular A)	
Sub-base (Granular B)	

Subgrade Conditions

Subgrade Type:	
Resilient Modulus by Material:	
Back calculated $M_{R:}$	
Lab M_R (override):	
Spring Testing (For FWD):	
Northern Subgrade Adjustment:	
Effective Subgrade Modulus:	
Subgrade Information source:	

Current Structural Condition (mm)

SN_{EFF} (Layer Info):	
SN_{EFF} (FWD Results):	
$SN_{Reg:}$	
SN Additional:	

Strengthening Required (mm)

Additional Asphalt Overlay:	
Strength Increase (SN):	
Total Structure Number (SN):	

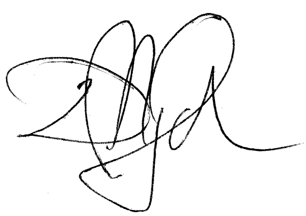
4.0 Responsibilities

Suggestions for changes to these Pavement Structure Design Guidelines are encouraged by sending them to the Director of Geotechnical Engineering Section.

CONTACT:

Daryl Finlayson, P. Eng.
Senior Materials & Pavement Engineer
Engineering Branch
Tel: (250) 387-4360
Daryl.Finlayson@gov.bc.ca

Sarah Gaib, P. Eng.
Senior Geotechnical Engineer
Engineering Branch
Tel: (250) 356-0390
Sarah.Gaib@gov.bc.ca



Dirk Nyland, P. Eng.
Chief Engineer

c.c. A.D.M. Highway Dept.
c.c. A.D.M. Planning & Major Projects
c.c. All Regional Directors
c.c. All Manager, Geotechnical & Materials Engineering

Appendix A

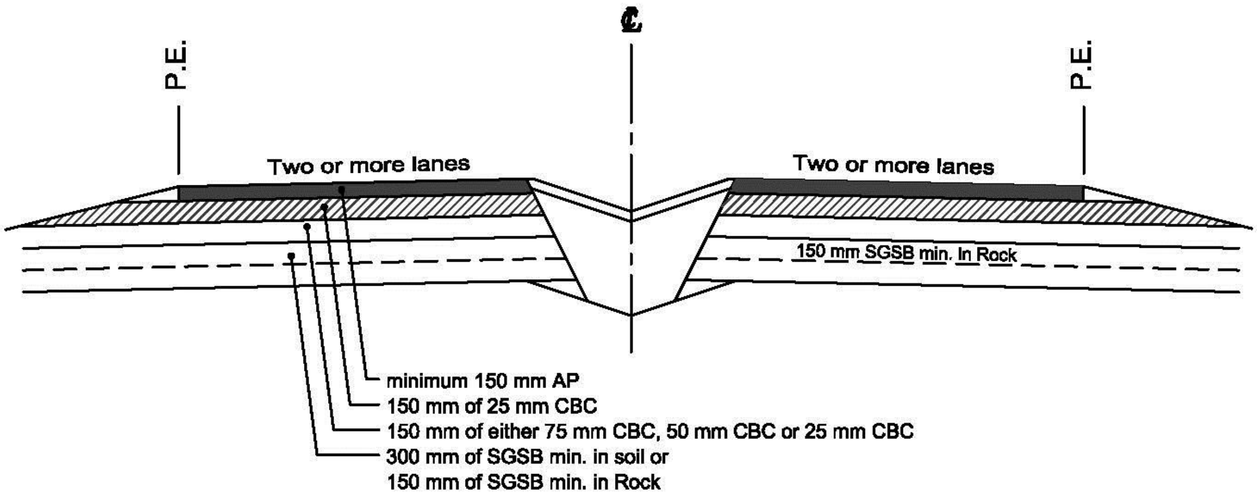
Pavement Structure Types A, B, C, and D

PAVEMENT STRUCTURE TYPE A:

Asphalt Pavement (AP) layer may exceed 150 mm depending on the specific traffic loading, project requirements and the ESAL's for a 20 year design period.

Typical Pavement Structure for Type A for

High Volume Roads
ESAL's ≥ 20,000,000

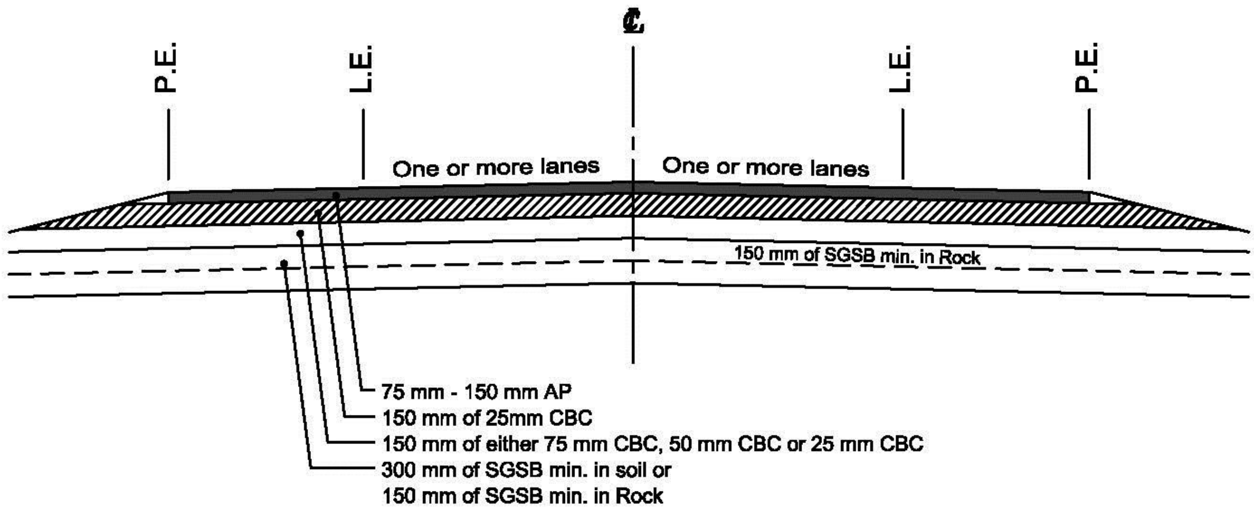


PAVEMENT STRUCTURE TYPE B:

Asphalt Pavement (AP) layer thicknesses may range from a minimum of 75 mm up to a maximum of 150 mm. Truck traffic may increase the asphalt layer thickness to a minimum of 100mm.

The design depth of asphalt layer needs to be determined based on the project, location, traffic loading, and ESAL's for a 20 year design period.

Typical Pavement Structure for Type B for **Medium to High Volume Roads**
ESAL's ≥ 100,000 and < 20,000,000



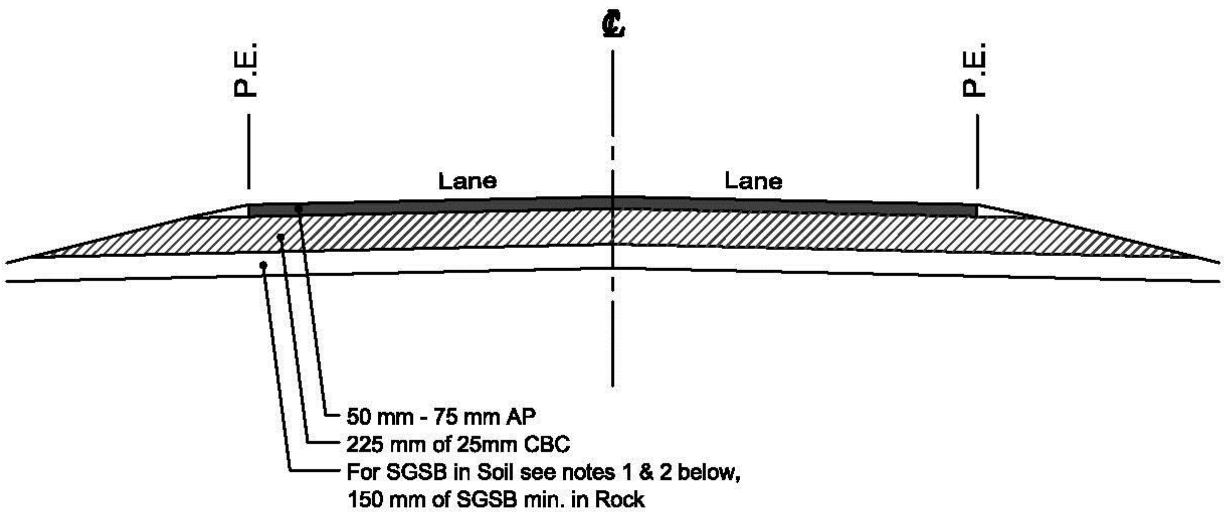
PAVEMENT STRUCTURE TYPE C:

Asphalt Pavement (AP) layer thicknesses may range from a minimum of 50 mm up to a maximum of 75 mm.

The design depth of asphalt layer needs to be determined based on the project, location and ESAL's for a 20 year design period.

Typical Pavement Structure for Type C for

<u>Low to Medium Volume Roads</u>
ESAL's < 100,000 Subdivision Roads
Infrequent use by heavy commercial vehicles



Note: 1. 150 mm of SGSB minimum on Coarse Grained Sub-grades (Unified Soils Classification System – GW/GP/GM/GC/SW/SP/SM/SC) where ground water does not pose a drainage problem and frost penetration does not affect the structure.

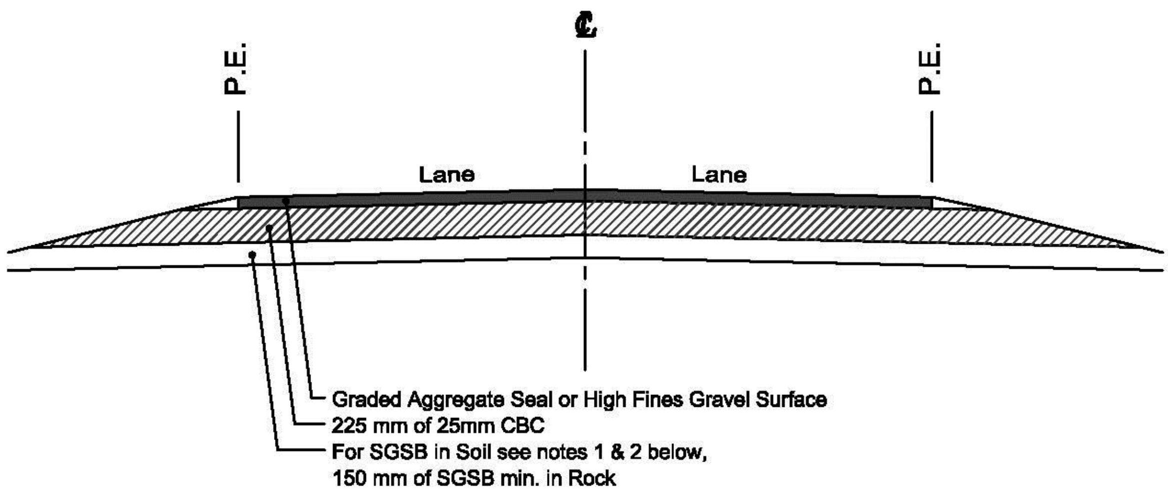
2. 300 mm of SGSB minimum on Fine Grained Sub-grades (Unified Soils Classification System – ML/CL/OL/MH/CH/OH).

PAVEMENT STRUCTURE TYPE D:

A double-pass seal coat (Graded Aggregate Seal or GAS) or a high fines gravel surface (HFSA) are options for surfacing of low-volume roads**.**

Typical Pavement Structure for Type D for

Low Volume Roads
ESAL's < 100,000
Infrequent use by heavy commercial vehicles



Note: 1. Gravel roads may use a high fines surfacing aggregate for its running surface if no aggregate sealcoat surface is applied.

2. 150 mm of SGSB minimum on Coarse Grained Sub-grades (Unified Soils Classification System – GW/GP/GM/GC/SW/SP/SM/SC) where ground water does not pose a drainage problem and frost penetration does not affect the structure.

3. 300 mm of SGSB minimum on Fine Grained Sub-grades (Unified Soils Classification System – ML/CL/OL/MH/CH/OH).