National Examinations – December 2019

16-Civ-A6, Highway Design, Construction and Maintenance

3 Hour Duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper a clear statement of any assumptions made.

2. Any data, not given but required, can be assumed.

3. This is a "CLOSED BOOK" examination. Candidates may use one of two calculators, the Casio or Sharp approved models.

4. A total of five solutions is required. Only the first five as they appear in your answer book will be marked.

5. All questions are of equal value.

6. For non-numerical questions, clarity and organization of the answer are important.

7. This exam booklet contains 17 pages (1 cover page, 3 question pages and 13 pages for the appendices). The appendices contain figures, tables and formulae that could be used for solving the different questions. The content of the appendices is independent of the question numbering.

Marking Scheme

All questions have an identical weight of 20 marks each. Individual marks for sub-questions, when applicable, are indicated in brackets for each question.

Question 1 [20 marks]:

The analysis of the road safety data for a two-lane highway in a rural area in Ontario indicated that there is an increase of collision rates with wild animals in that area which represent a major concern for both humans and wildlife. The section where the problem has been identified is characterized by vertical curve the has the following features:

- Length of the vertical curve: L = 200m
- Grade before the curve is -3.5%
- Grade after the curve is 2.5%
- Design speed is 100 km/h and posted speed is 90 km/h

Based on the provided information:

a) [5 marks] What is the type of this vertical curve? Explain briefly the design concepts for this type of curves.
b) [5 marks] Calculate the safe stopping sight distance that this curve allows.
c) [5 marks] Would you consider that this curve is safe? Justify your answer.
d) [5 marks] What would explain the increase of the collision rate and what are the possible measure to improve the safety on this vertical curve?

Assume that the headlight height of the design vehicle is 60 cm and the upward divergence of the light beam is 1°.

Question 2 [20 marks]:

The first year AADT on a 4-lane freeway located in an urban area is expected to be 65,000 veh/day. The growth rate of the two-axle, 4-tire, single unit trucks is expected to be 1.5% per annum during the five years of the pavement life and will increase to 3% per annum for the remaining life of the pavement. The growth rate for all other categories of vehicles is expected to be 2% per annum throughout the life of the pavement. The design life of the pavement is 25 years and the projected vehicle mix during the first year is:

- Passenger cars = 50%
- Single-unit trucks, two-axle, four-tire = 20%
- Single-unit trucks, two-axle, six-tire = 15%
- Tractors semi-trailers, All multiple units = 15%

a) [5 marks] Explain the concept of the Equivalent Single Axle Load used in the AASHTO 1993 Pavement Design Method
b) [10 marks] Determine the design ESAL for the service life of the pavement
c) [5 marks] What is the new way for traffic analysis in the AASHTO-ME Design Method and how is it different from ESAL?

Question 3 [20 marks]:

Design a flexible pavement to carry a design ESAL of 10,000,000, over a design period of 20 years, based on the following information:

- The effective resilient modulus of the subgrade Mr = 7,000 psi
- The subbase layer is an untreated silty sand with a resilient modulus (ESB) of 20,000 psi
- The base layer is a cement-treated base with an unconfined compressive strength of at 7 days of 450 psi
- The elastic modulus of the asphalt concrete at 20°C (EAC) is 400,000 psi
- The pavement structure will be exposed to moisture levels approaching saturation for 25% of the time and the quality of drainage is poor
- Initial Serviceability index value: $p_0 = 4.5$
- Terminal Serviceability index value: $p_t = 3.0$
- Reliability and Standard Deviation: R = 90% and $S_0 = 0.4$

Assume reasonably any missing information and justify your assumptions.

Question 4 [20 marks]:

A 3 km curved section of an expressway in an urban area is characterized by a radius of 650 m (to the centreline of the road). According to the MTO study on provincial highway volumes in 2016, the estimated AADT of this section is 111,200 vehicles/day. The highway is a six-lane divided highway with a posted speed of 100 km/h and a maximum superelevation of 0.06. The width of each travelled lane is 3.75 m and the width of the median is 3m. This section is mainly in a fill area with a slope of 5:1 in the clear zone.

a) [7 marks] Would you consider that the radius of this curve is safe?
b) [7 marks] What length of the spiral curve between the tangent sections and the circular curve would you recommend?
c) [6 marks] What is the recommended width of the clear zone (CZ) at the outer side of the travelled roadway?

Question 5 [20 marks]:

A Plain Jointed Concrete Pavement is to be designed using the AASHTO 93 Pavement Design Method to withstand a traffic of 12,000,000 ESALs. The slabs are connected longitudinally and transversally using dowel and tie bars and asphalt shoulders were used. The geotechnical investigation conducted before the construction indicated that the subgrade is composed of clay with high plasticity (Class CH according to USCS) and that the bedrock layer was found at six feet from the surface of the subgrade.

Determine the thickness of the concrete slab to withstand the projected traffic.

The following information and design assumptions are available:

- Concrete slab: $E_c = 3.6 \times 10^6$, $S'_c = 600$ psi
- Unbound Granular Subbase: $D_{SB} = 10$ in., $E_{SB} = 30,000$ psi.
- Resilient Modulus of the Subgrade: MR = 5,000 psi.
- Initial Serviceability index value: $p_0 = 4.5$
- Terminal Serviceability index value: $p_t = 2.5$
- Reliability and Standard Deviation: R = 90% and $S_0 = 0.3$

- The quality of the drainage is good and the pavement is exposed to moisture level approaching saturation for 15% of the time.

Question 6 [20 marks]:

The PGAC grading system for asphalt cements is now in use in Ontario for more than 15 years. In addition, both the Superpave and Marshall mix design methods are still used by MTO and municipalities. Based on your knowledge, briefly answer the following questions about the PGAC grading system and the mix design practice:

a) [5 marks] The PGAC is a performance-based grading system. What does that mean? How this grading system differs from the previous penetration grading system used in Ontario?

b) [2 marks] A binder has been tested to determine its PG grade. The test results showed that the binder meets the criteria for a temperature as high as 68.3°C and also meets the criteria for a temperature as low as –33.9°C. What would be the PG grade of this binder?

c) [5 marks] What are the principal tests used in PGAC system and what is the targeted property by each of these tests?

In the document entitled "The ABC's of PGAC" published by the Ontario Asphalt Pavement Council, it is indicated that "It will be several years before Superpave volumetric mix design replaces the well-known Marshall method of mix design". In our days, some municipalities continue to use Marshall while MTO and other Ontarian municipalities use the Superpave Mix Design Method.

d) [8 marks] Describe briefly each of the two methods and prepare a table summarizing the pros and cons of each method.

Question 7:

A two-lane secondary rural highway is to be constructed in Ontario for a cumulative ESAL 600,000. The subgrade Unified Soil Classification System is CL and the CBR is around 6. The soil is frost susceptible and the thickness of the pavement should not be less than 600mm.

a) [6 marks] Explain briefly the frost-heave action of pavements and describe some of the potential measures or solutions to prevent it.

b) [6 marks] Determine the required thickness of the different pavement layers using the TAC typical pavement designs in page 13.

c) [8 marks] Using the and Granular Base Equivalency (GBE) concept (page 14), propose an alternative design if you know that good aggregates for the subbase layer in the region are scarce and expensive while an asphalt plant is very close to the site which would reduce the transportation cost of the asphalt.

Appendix

Pavement Design: Tables and Figures

$$ESAL = AADT \times HVP \times DF \times TF \times TDY$$

$$Cumulative\ ESALs = Initial\ year\ ESAL_{(Design\ Lane)} \times \frac{[(1+g)^t - 1]}{g}$$

$$\Delta PSI = p_o - p_t$$

$$u_f = 1.18 \times 10^8 M_R^{-2.32}$$

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 + \cdots + a_i D_i m_i$$

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

DISTRIBUTION OF TRUCK FACTORS (TF) FOR DIFFERENT CLASSES OF HIGHWAYS AND VEHICLES—UNITED STATES*

Vehicle Type	Truck Factors: Rural Systems: Interstate	Rural: Other Principal	Rural: Minor Arterial	Rural: Collectors: Major	Rural: Collectors: Minor	Rural: Range	Urban Systems: Interstate	Urban: Other Freeways	Urban: Other Principal	Urban: Minor Arterial	Urban: Collectors	Urban: Range
Single-unit trucks												
2-axle, 4-tire	0.003	0.003	0.003	0.017	0.003	0.003-0.017***	0.002	0.015	0.002	0.008	—	0.006-0.015***
2-axle, 6-tire	0.21	0.25	0.28	0.41	0.19	0.19-0.41	0.17	0.13	0.24	0.23	0.13	0.13-0.24
3-axle or more	0.61	0.86	1.06	1.26	0.45	0.45-1.26	0.61	0.74	1.02	0.76	0.72	0.61-1.02
All single-units	0.06	0.06	0.08	0.12	0.03	0.03-0.12	0.05	0.06	0.09	0.04	0.16	0.04-0.16***
Tractor semi-trailers												
4-axle or less	0.62	0.92	0.62	0.37	0.91	0.37-0.91	0.98	0.48	0.71	0.46	0.40	0.40-0.98
5-axle**	1.09	1.25	1.05	1.67	1.11	1.05-1.67	1.07	1.17	0.97	0.77	0.63	0.63-1.17
6-axle or more**	1.23	1.54	1.04	2.21	1.35	1.04-2.21	1.05	1.19	0.90	0.64	—	0.64-1.19
All multiple units	1.04	1.21	0.97	1.52	1.08	0.97-1.52	1.05	0.96	0.91	0.67	0.53	0.53-1.05
All trucks	0.52	0.38	0.21	0.30	0.12	0.12-0.52	0.39	0.23	0.21	0.07	0.24	0.07-0.39

**Compiled from data supplied by the Highway Statistics Division, U.S. Federal Highway Administration.*

***Including full-trailer combinations in some states.*

****See Article 4.06 for values to be used when the number of heavy trucks is low.*

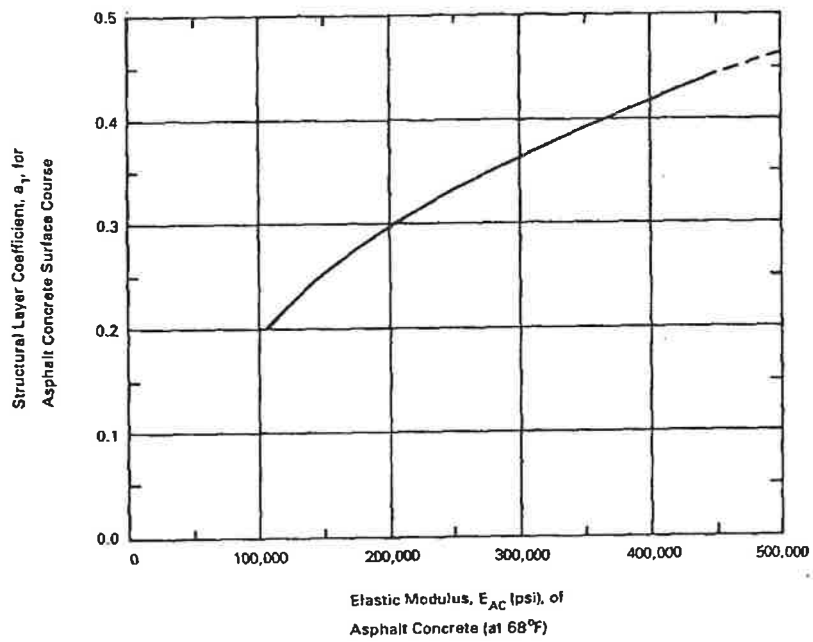
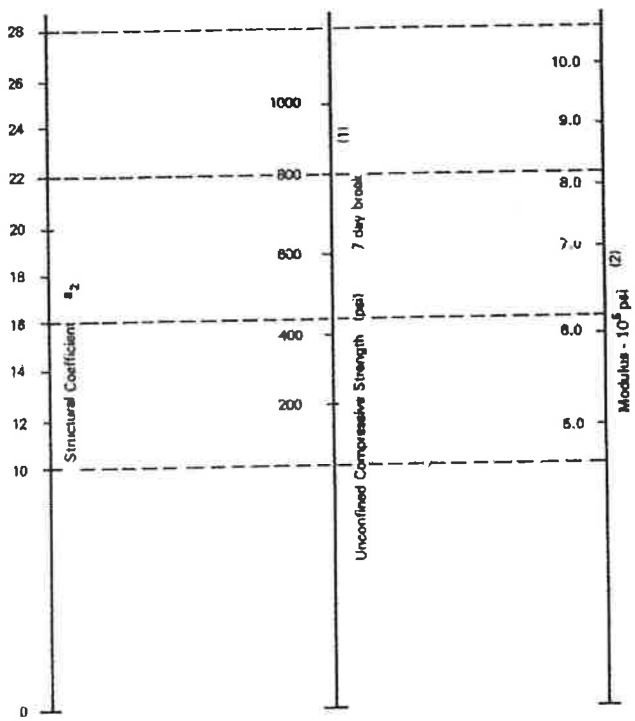
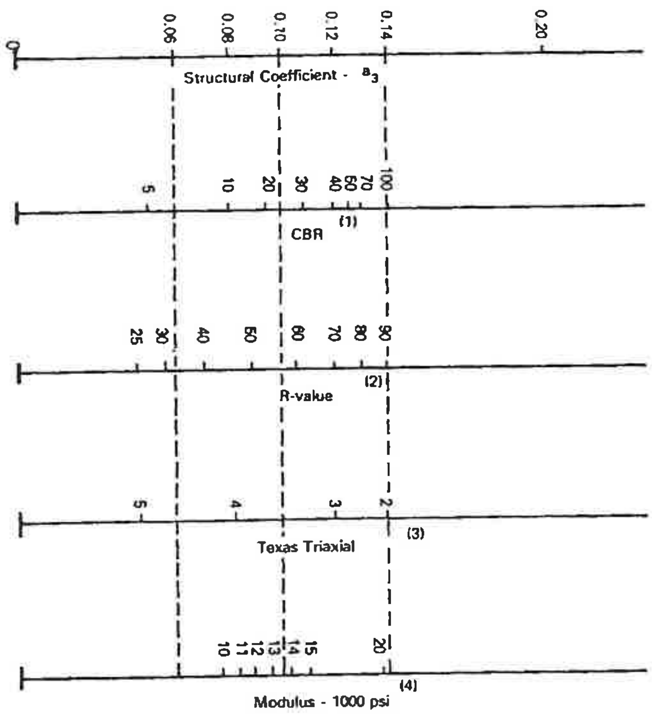


Chart for Estimating Structural Layer Coefficient of Dense-Graded Asphalt Concrete Based on the Elastic (Resilient) Modulus (*3*)



(1) Scale derived by averaging correlations from Illinois, Louisiana and Texas.
(2) Scale derived on NCHRP project (3)

Variation in a for Cement-Treated Bases with Base Strength Parameter (*3*)



(1) Scale derived from correlations from Illinois.
(2) Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico and Wyoming.
(3) Scale derived from correlations obtained from Texas.
(4) Scale derived on NCHRP project (3).

Variation in Granular Subbase Layer Coefficient (a_3) with Various Subbase Strength Parameters (3)

Recommended m_i Values for Modifying Structural Layer Coefficients of Untreated Base and Subbase Materials in Flexible Pavements

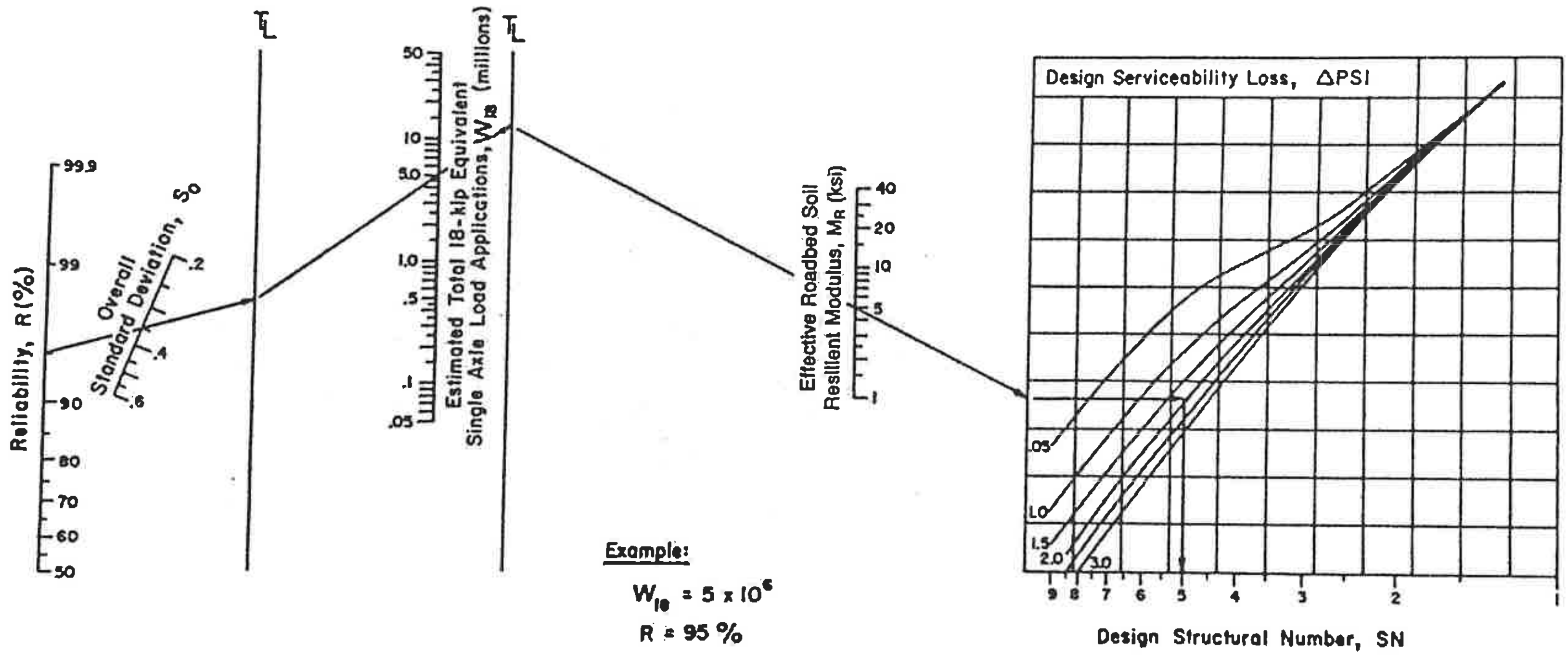
	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
Quality of Drainage	Less Than 1%	1–5%	5–25%	Greater Than 25%
Excellent	1.40–1.35	1.35–1.30	1.30–1.20	1.20
Good	1.35–1.25	1.25–1.15	1.15–1.00	1.00
Fair	1.25–1.15	1.15–1.05	1.00–0.80	0.80
Poor	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very poor	1.05–0.95	0.95–0.75	0.75–0.40	0.40

Minimum Thickness (inches)

Traffic, ESAL's	Asphalt Concrete	Aggregate Base
Less than 50,000	1.0 (or surface treatment)	4
50,001–150,000	2.0	4
150,001–500,000	2.5	4
500,001–2,000,000	3.0	6
2,000,001–7,000,000	3.5	6
Greater than 7,000,000	4.0	6

NOMOGRAPH SOLVES:

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



Example:

$W_{18} = 5 \times 10^6$

$R = 95\ \%$

$S_o = 0.35$

$M_R = 5000$ psi

$\Delta PSI = 1.9$

Solution: SN = 5.0

Design Chart for Flexible Pavements Based on Using Mean Values for Each Input

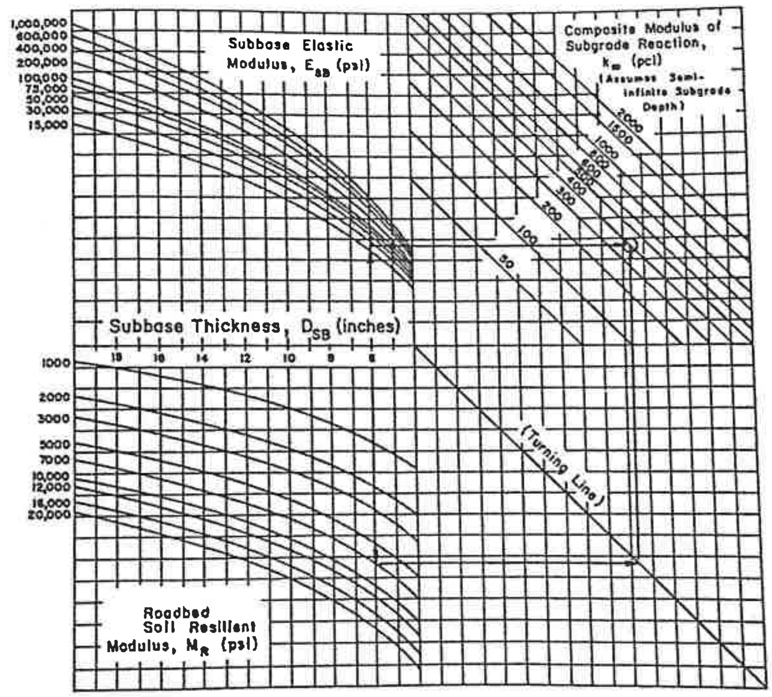


Chart for Estimating Composite Modulus of Subgrade Reaction, k_∞, Assuming a Semi-Infinite Subgrade Depth. (For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)

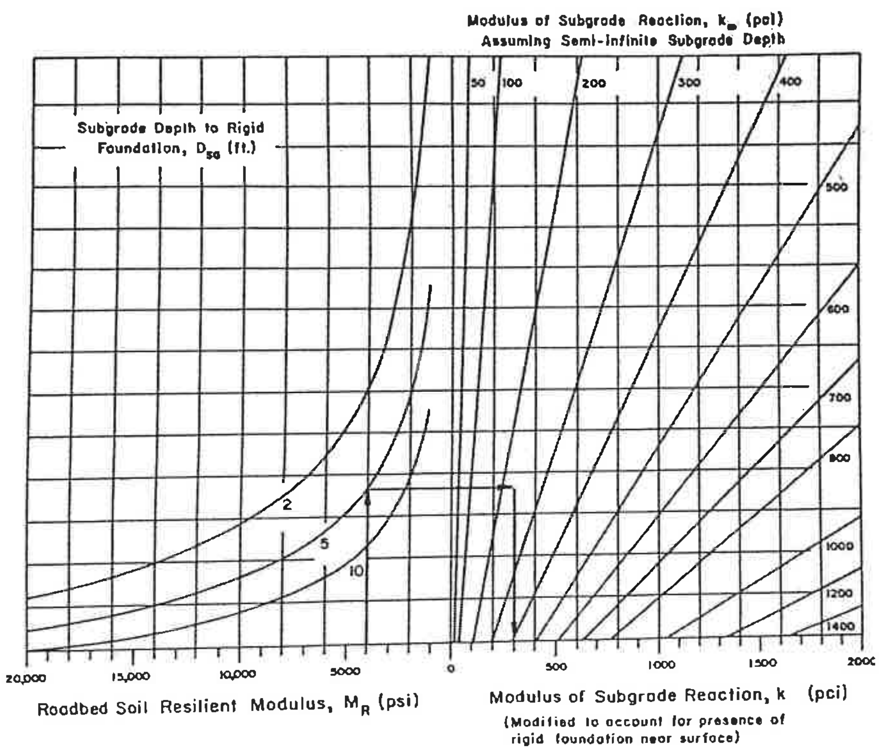
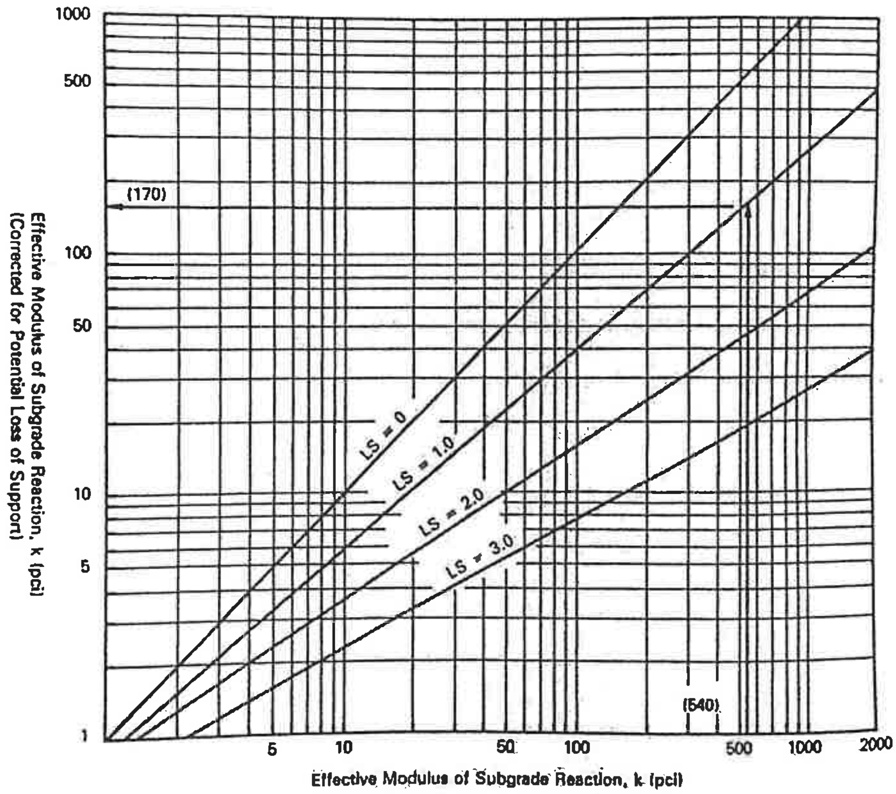


Chart to Modify Modulus of Subgrade Reaction to Consider Effects of Rigid Foundation Near Sur



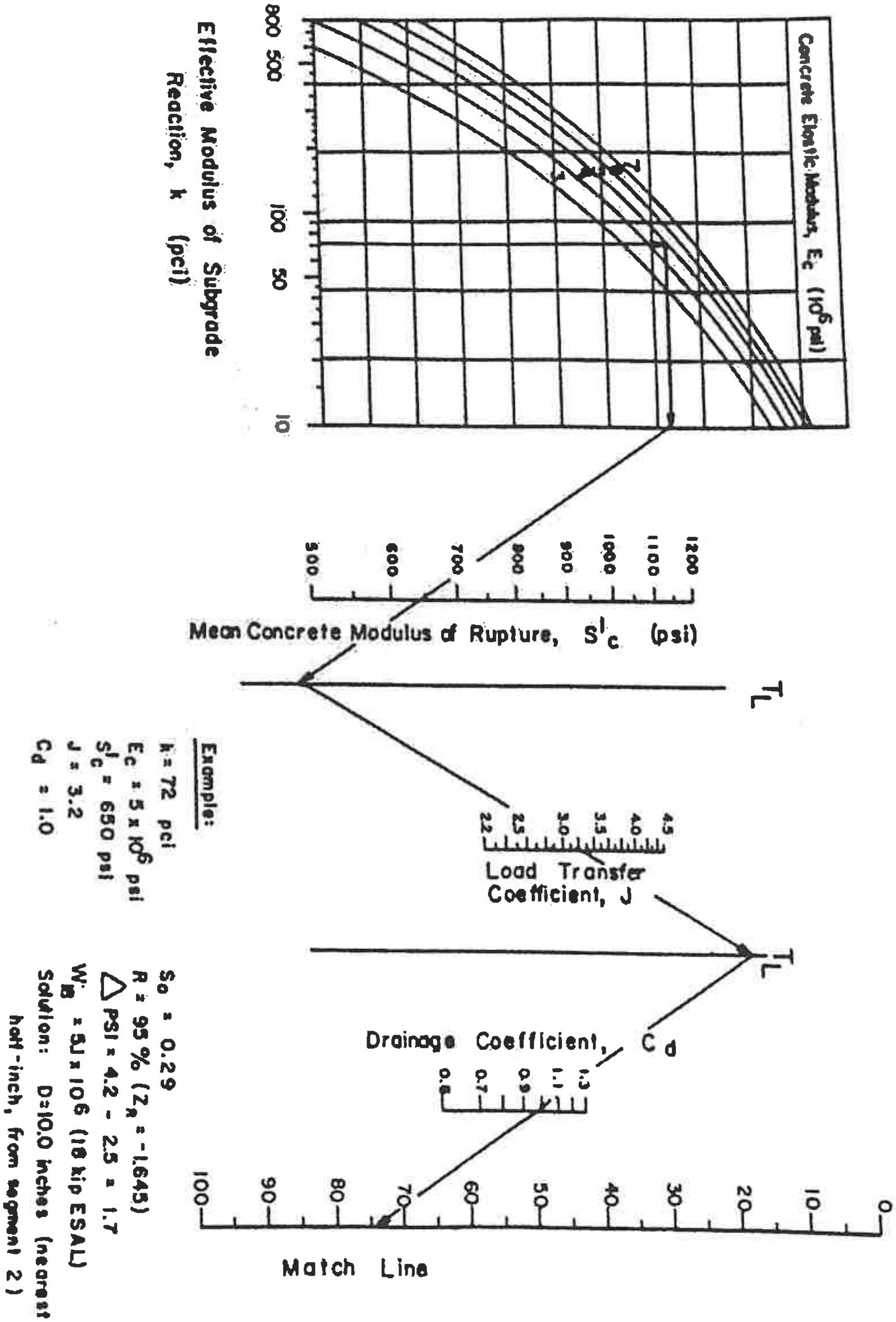
Correction of Effective Modulus of Subgrade Reaction for Potential Loss of Subbase Support

Recommended Values of Drainage Coefficient, C_d, for Rigid Pavement Design

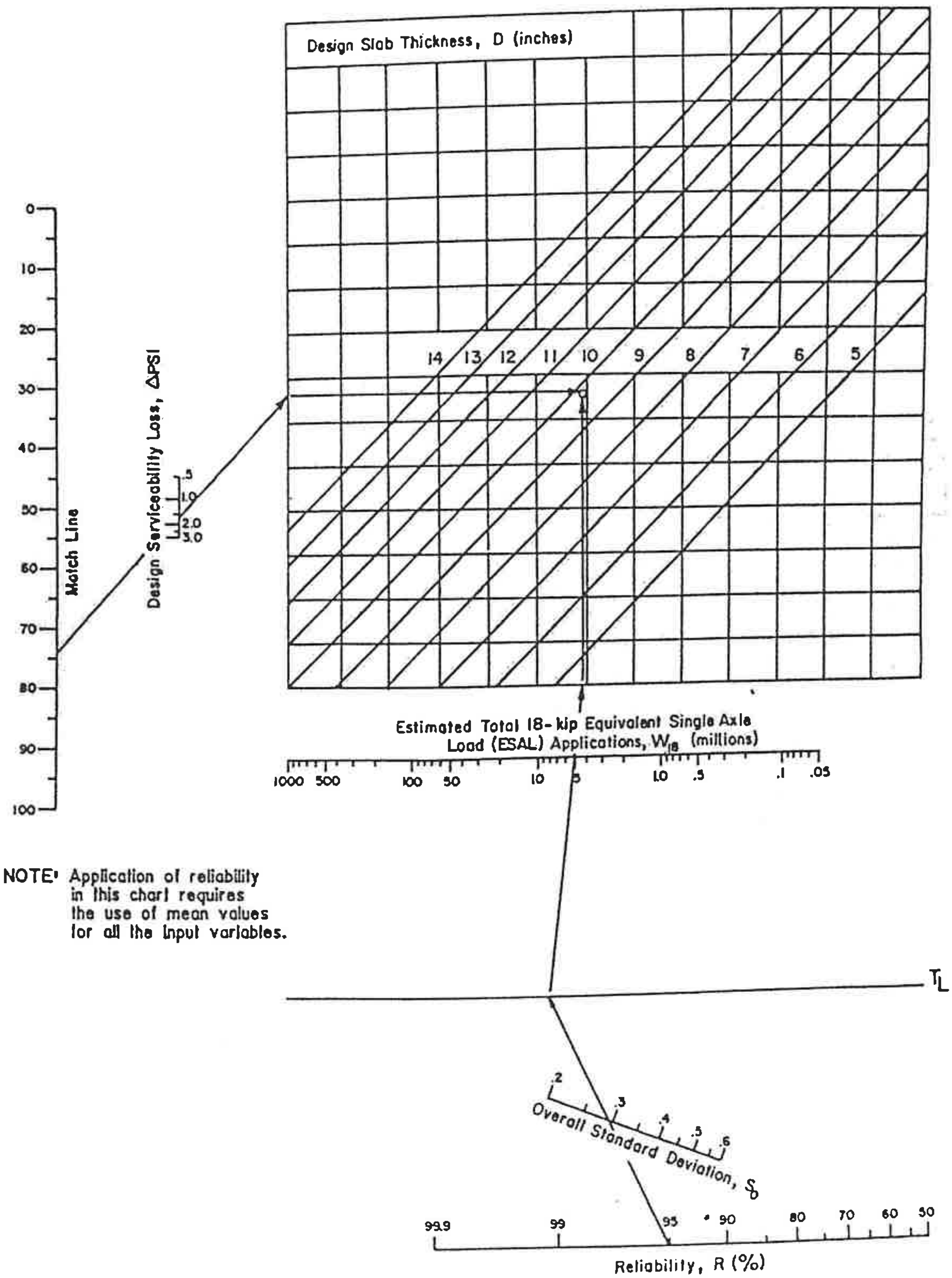
Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation: Less Than 1%	1–5%	5–25%	Greater Than 25%
Excellent	1.25–1.20	1.20–1.15	1.15–1.10	1.10
Good	1.20–1.15	1.15–1.10	1.10–1.00	1.00
Fair	1.15–1.10	1.10–1.00	1.00–0.90	0.90
Poor	1.10–1.00	1.00–0.90	0.90–0.80	0.80
Very poor	1.00–0.90	0.90–0.80	0.80–0.70	0.70

Recommended Load Transfer Coefficient for Various Pavement Types and Design Conditions

Shoulder	Asphalt		Tied P.C.C.	
Load Transfer Devices	Yes	No	Yes	No
Pavement Type				
1. Plain jointed and jointed reinforced	3.2	3.8–4.4	2.5–3.1	3.6–4.2
2. CRCP	2.9–3.2	N/A	2.3–2.9	N/A



Design Chart for Rigid Pavement Based on Using Mean Values for Each Input Variable (Segment 1)



Continued—Design Chart for Rigid Pavements Based on Using Mean Values for Each Input Variable (Segment 2)

Typical pavement thicknesses (mm) used by provincial agencies for cumulative ESALs of 0.5×10^6.

Subgrade Type	Conventional Pavement Structure Course	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NF	YT**	PW*** & GSC
"Weak"	Asphalt concrete	75	80	Seal*	85	90	85	140	100		80	100	50
Lacustrine Clay	Asph. stab. gran.		50										
CBR ≤ 3.0	Granular base	300	300	150	150	150	150	150	150		100	150	150
Group Index ~ 20	Granular subbase			470	300	450-600	450-600	450	250	n/a	200		200
Unified Soil Class.-CH	Select granular	300										450	
	Total	675	430	620	535	690-840	685-835	740	500		380	700	400
"Medium"	Asphalt concrete	75	80	Seal**	85	90	85	140	100		80	100	50
Glacial Till	Asph. stab. gran.		50										
CBR ≤ 5	Granular base	300	200	150	100	150	150	150	150		100	150	150
Group Index ~ 10-12	Granular subbase			320	200	450	450-600	450	200	n/a	200		150
Unified Soil Class.-CL	Select granular	300										300	
	Total	675	330	470	385	690	685-835	740	450		380	550	350
"Strong"	Asphalt concrete	75	60	Seal**	85	90	85	140	100		80	100	50
Clayey Gravel	Asph. stab. gran.		50										
CBR ≥ 20	Granular base	300	150	200	100	150	150	150	150		100	150	150
Group Index ~	Granular subbase				100		300-450	450	200	n/a	200		
Unified Soil Class.-GC	Select granular	0-300										150	
	Total	375-675	280	200	285	240	535-685	740	450		380	400	200

* A double seal on base would be used as the surface for up to 1500 AADT

** Yukon has alternative designs of Bituminous Surface Treatment (BST) on 200 mm of granular base on 450, 300 and 150 mm of select granular, respectively, for the three subgrade types

*** Public Works and Goverment Services Canada

Typical pavement thicknesses (mm) used by provincial agencies for cumulative ESALs of 1×10^6.

Subgrade Type	Conventional Pavement Structure Course	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NF	YT*	PW & GSC
"Weak"	Asphalt concrete	100	100	100	100	130	105	140	150		120	100	100
Lacustrine Clay	Asph. stab. gran.		50										
CBR ≤ 3.0	Granular base	300	300	150	175	150	200	150	150		150	150	200
Group Index ~ 20	Granular subbase			360	350	450-600	525-675	450	300		300	150	450
Unified Soil Class.-CH	Select granular	300								n/a	500	450	
	Total	700	450	610	625	730-880	830-980	740	600		1070	850	750
"Medium"	Asphalt concrete	100	90	80	100	130	105	140	150		120	100	100
Glacial Till	Asph. stab. gran.		50										
CBR ≤ 5	Granular base	300	230	150	150	150	200	150	150		150	150	200
Group Index ~ 10-12	Granular subbase			260	225	450	525-675	450	250		300	150	300
Unified Soil Class. -CL	Select granular	300								n/a	500	300	
	Total	700	370	490	475	730	830-980	740	550		1070	700	600
"Strong"	Asphalt concrete	100	80	60	100	130	105	140	125		120	100	100
Clayey Gravel	Asph. stab. gran.		50										
CBR ≥ 20	Granular base	300	200	180	100	150	200	150	150		150	150	150
Group Index ~ 2	Granular subbase				100	150	300-450	450	200		300	150	150
Unified Soil Class. -GC	Select granular	0-300								n/a	500	150	
	Total	400-700	330	240	300	430	605-755	740	475		1070	550	400

* Yukon has alternative designs of Bituminous Surface Treatment (BST) on 300 mm of granular base on 450, 300 and 150 mm of select granular, respectively, for the three subgrade types.

Typical pavement thicknesses (mm) used by provincial agencies for cumulative ESALs of 10×10^6.

Subgrade Type	Conventional Pavement Structure Course	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NF	YT	PW & GSC
"Weak"	Asphalt concrete	100	120	150	125	180	180	140	200			125	150
Lacustrine Clay	Asph. Stab. Gran.		50										
CBR ≥ 3.0	Granular base	300	400	200	175	150	250	150	150			150	200
Group Index ~ 20	Granular subbase			390	350	600-800	525-900	450	500	n/a	n/a	150	600
Unified Soil Class.-CH	Select granular	650											
	Total	1050	570	740	650	930-1130	955-1330	740	850			875	950
"Medium"	Asphalt concrete	100	120	130	125	180	180	140	200			125	150
Glacial Till	Asph. Stab. Gran.		30										
CBR ≥ 5	Granular base	300	230	200	150	150	250	150	150			150	200
Group Index ~ 10-12	Granular subbase			280	225	450-600	525-675	450	300	n/a	n/a	150	400
Unified Soil Class.-CL	Select granular	425										300	
	Total	825	400	610	500	780-930	955-1105	740	650			725	750
"Strong"	Asphalt concrete	100	100	90	125	180	180	140	200			125	150
Clayey Gravel	Asph. Stab. Gran.		50										
CBR ≥ 20	Granular base	300	230	230	100	150	250	150	150			150	200
Group index ~ 2	Granular subbase				100	300	300-450	450	200	N/A	N/A	150	300
Unified Soil Class.-GC	Select granular	0-300										150	
	Total	400-700	400	330	325	630	730-880	740	550		0	525	650

Approximate layer equivalencies used by various agencies for new pavement designs

Provincial Agency	Component Layer Material Ratio Actual Thickness = Granular Base Equivalency (GBE) **
British Columbia	2.00 asphalt concrete 1.00 well-graded gravel base 1.70 asphalt treated base course 1.10 intermediate graded base 1.20 open graded base 0.70 pit run subbase
Alberta	2.25 asphalt concrete 1.00 crushed gravel (granular base) 1.30 soil cement 1.80 asphalt treated gravel base
Saskatchewan	Considered as a variable and therefore not used.
Manitoba	2.00 asphalt concrete 1.00 gravel base 1.33 sand asphalt or soil cement
Ontario	2.00 asphalt concrete 1.80 treated base (PC) 1.50 treated base (asphalt) 1.00 granular base 0.67 granular subbase 1.00 OGDL
Quebec***	2.00 asphalt concrete 1.25 crushed rock base 1.00 gravel base or subbase 0.50 sand subbase 2.00 soil cement (150 mm or less) 1.25 soil cement (more than 150 mm) 0.75 lime stabilized clay 1.40 asphalt stabilized base
New Brunswick	2.00 asphalt concrete 1.00 crushed rock 1.00 soil cement (150 mm or over) 1.00 asphalt stabilized base 0.67 gravel subbase
PEI	2.00 asphalt concrete 1.00 crushed rock 0.67 crushed gravel 1.00 soil cement 1.00 asphalt stabilized base
Newfoundland	2.50 asphalt concrete 1.00 graded crushed rock 1.00 graded crushed gravel 0.83 gravel subbase 0.63 sandy gravel

** i.e., 1 mm of pit run subbase (B.C.) = 0.7 mm of granular base
*** The GBE's for Quebec are approximations that have been used in the past. Currently, however, Quebec considers this a variable, the same as Saskatchewan.

Geometric design: Tables and Figures

$d_b = \dfrac{v^2}{2g(f+G)}$	$K = \dfrac{L}{\Delta G}$ or $\dfrac{L}{A}$
$L_{crest} = \dfrac{SSSD^2 \times A}{200(H + h_1 + 2\sqrt{H \times h_1})}$	$K = \dfrac{SSSD^2}{200(\sqrt{H} + \sqrt{h_1})^2}$
$L_{sag} = \dfrac{SSSD^2 \times A}{200(H + SSSD\ Tan\beta)}$	$R = \dfrac{V^2}{127(e+\mu)}$
$A^2 = L_s R = \dfrac{2RV \times 1000}{3600}$	$A = \sqrt{0.03577V^3}$
$L_s = \dfrac{we}{2s}$; $A^2 = R \times L_s$	$A = \sqrt{\dfrac{RV}{1.8}}$
$S = 2R\theta^\circ\left(\dfrac{\pi}{180}\right)$	$\theta = \dfrac{28.65}{R}S$
$m = R(1 - \cos\dfrac{28.65}{R}S)$	

Relative Slope Values

Design speed (km/h)	60	80	90	≥ 100
Relative slope (m/m)	0.006	0.0051	0.0047	0.0044

Friction Coefficients to be used in questions

Vehicle Speed (km/h)	≤ 60	70	80	90	100	110	120
Stopping Coefficient of Friction	0.38	0.37	0.35	0.31	0.30	0.28	0.27
Coefficient of Side Friction	0.17	0.16	0.15	0.12	0.11	0.09	0.07

Clear zone distances for straight sections (m)

Design Speed (Km/h)	Design AADT *	Fill Slopes			Cut Slopes		
		6:1 or Flatter	5:1 to 4:1	3:1	3:1	5:1 to 4:1	6:1 or Flatter
60 or less with barrier curb***	All	0.5	0.5	0.5	0.5	0.5	0.5
60 or Less	Under 750	2.0 – 3.0	2.0 – 3.0	**	2.0 – 3.0	2.0 – 3.0	2.0 – 3.0
	750 – 1500	3.0 – 3.5	3.5 – 4.5	**	3.0 – 3.5	3.0 – 3.5	3.0 – 3.5
	1500 – 6000	3.5 – 4.5	4.5 – 5.0	**	3.5 – 4.5	3.5 – 4.5	3.5 – 4.5
	Over 6000	4.5 – 5.0	4.5 – 5.0	**	4.5 – 5.0	4.5 – 5.0	4.5 – 5.0
70 –80	Under 750	3.0 – 3.5	3.5 – 4.5	**	2.5 – 3.0	2.5 – 3.0	3.0 – 3.5
	750 – 1500	4.5 – 5.0	5.0 – 6.0	**	3.0 – 3.5	3.5 – 4.5	4.5 – 5.0
	1500 – 6000	5.0 – 5.5	6.0 – 8.0	**	3.5 – 4.5	4.5 – 5.0	5.0 – 5.5
	Over 6000	6.0 – 6.5	7.5 – 8.5	**	4.5 – 5.0	5.5 – 6.0	6.0 – 6.5
90	Under 750	3.5 – 4.5	4.5 – 5.5	**	2.5 – 3.0	3.0 – 3.5	3.0 - 3.5
	750 – 1500	5.0 – 5.5	6.0 – 7.5	**	3.0 – 3.5	4.5 – 5.0	5.0 – 5.5
	1500 – 6000	6.0 – 6.5	7.5 – 9.0	**	4.5 – 5.0	5.0 – 5.5	6.0 – 6.5
	Over 6000	6.5 – 7.5	8.0 – 10.0 *	**	5.0 – 5.5	6.0 – 6.5	6.5 – 7.5
100	Under 750	5.0 – 5.5	6.0 – 7.5	**	3.0 – 3.5	3.5 – 4.5	4.5 – 5.0
	750 – 1500	6.0 – 7.5	8.0 – 10.0 *	**	3.5 – 4.5	5.0 – 5.5	6.0 – 6.5
	1500 – 6000	8.0 – 9.0	10.0 – 12.0 *	**	4.5 – 5.5	5.5 – 6.5	7.5 – 8.0
	Over 6000	9.0 – 10.0 *	11.0 – 13.5 *	**	6.0 – 6.5	7.5 – 8.0	8.0 – 8.5
110	Under 750	5.5 - 6.0	6.0 – 8.0	**	3.0 – 3.5	4.5 – 5.0	4.5 – 4.9
	750 – 1500	7.5 – 8.0	8.5 – 11.0 *	**	3.5 – 5.0	5.5 – 6.0	6.0 – 6.5
	1500 – 6000	8.5 – 10.0 *	10.0 – 13.0 *	**	5.0 – 6.0	6.5 – 7.5	8.0 – 8.5
	Over 6000	9.0 – 10.5 *	11.0 – 14.0 *	**	6.5 – 7.5	8.0 – 9.0	8.5 – 9.0
120 or More	750 – 1500 *	8.0 – 9.0	9.0 – 12.0	**	3.5 – 5.0	6.0 – 6.5	7.0 – 7.5
	1500 – 6000 *	9.0 – 10.0	10.0 – 14.0	**	5.5 – 6.5	7.0 – 8.0	8.0 – 9.0
	Over 6000 *	10.0 – 11.0 *	11.0 – 15.0	**	7.0 – 8.0	8.5 – 9.5	9.0 – 10.0

Horizontal Curve Adjustments for Clear Zone Distances[4]

Radius (m)	Design Speed 60	70	80	90	100	110 +
900	1.1	1.1	1.1	1.2	1.2	1.2
700	1.1	1.1	1.2	1.2	1.2	1.3
600	1.1	1.2	1.2	1.2	1.3	1.4
500	1.1	1.2	1.2	1.3	1.3	1.4
450	1.2	1.2	1.3	1.3	1.4	1.5
400	1.2	1.2	1.3	1.3	1.4	
350	1.2	1.2	1.3	1.4	1.5	
300	1.2	1.3	1.4	1.5	1.5	
250	1.3	1.3	1.4	1.5		
200	1.3	1.4	1.5			
150	1.4	1.5				
100	1.5					

Note: The clear zone horizontal curve adjustment factor is applied to the outside of curves only. Curves flatter than 900 m do not require an adjusted clear zone.

K Factors to Provide Minimum Stopping Sight Distance on Sag Vertical Curves[1]

Design Speed (km/h)	Assumed Operating Speed (km/h)	Stopping Sight Distance (m)	Rate of Sag Vertical Curvature (K)			
			Headlight Control		Comfort Control	
			Calculated	Rounded	Calculated	Rounded
30	30	29.6	3.9	4	2.3	2
40	40	44.4	7.1	7	4.1	4
50	47-50	57.4-62.8	10.2-11.5	11-12	5.6-6.3	5-6
60	55-60	74.3-84.6	14.5-17.1	15-18	7.7-9.1	8-9
70	63-70	99.1-110.8	19.6-24.1	20-25	10.0-12.4	10-12
80	70-80	112.8-139.4	24.6-31.9	25-32	12.4-16.2	12-16
90	77-90	131.2-168.7	29.6-40.1	30-40	15.0-20.5	15-20
100	85-100	157.0-205.0	36.7-50.1	37-50	18.3-25.3	18-25
110	91-110	179.5-246.4	43.0-61.7	43-62	21.0-30.6	21-30
120	98-120	202.9-285.6	49.5-72.7	50-73	24.3-36.4	24-36
130	105-130	227.9-327.9	56.7-85.0	57-85	27.9-42.8	28-43