Highway and Railway Design 1 **EXERCISES 5.** (for Lecture 10. of **Dr. A. Timár)**

1. Example

The number of load repetition observed in a day on a given road section by 100 kN Standard Axle Load (SAL) is 1000, 110 kN axle load is 120 and 50 kN axle load is 11000. Find the equivalent axle load (ESAL).

Solution

Item	Axle load *(L; kN)*	No. of load repetition *(n_i)*	Load Equivalency Factor – LEF $F_i = (L/SAL)^4$	ESAL/day *($F_i n_i$, kN)*
1	50	11000	$(50/100)^4 = 0.0625$	688
2	100	1000	$(100/100)^4 = 1.0$	1000
3	110	120	$(110/100)^4 = 1.464$	176
Σ				**1864**

2. Example

The Average Annual Daily Traffic (*AADT*) expected on a two-lane road section in the first calendar year following reconstruction is 1800 PCU/day, from which the rate of Commercial Vehicles (*CV*) by 20+50 kN axle load is 8%, by 20+50+50 kN axle load is 4% and by 50+80+110+110 kN axle load is 3%. Calculate the Design Traffic (N_{DT}) for a 15 year long Design Period, assuming the composition of traffic remains constant and its cumulative traffic growth factor (*CGF*) is 2%/year.

Solution

a) First calculate the ESAL in the base year:

Item	AADT *(PCU=2.5CV; veh/day)*	Axle load *(L; kN)*	Yearly number of load repetition *(365*AADT)*	Load Equivalency Factor – LEF $F_i = (L/SAL)^4$	ESAL/year *($F_i n_i$; kN)*
1	(0.08*1800)/2.5= 58	20	21 024	$(20/100)^4 = 0.0016$	34
		40		$(40/100)^4 = 0.0256$	539
2	(0.04*1800)/2.5= 29	20	10 512	$(20/100)^4 = 0.0016$	17
		40		$(40/100)^4 = 0.0256$	270
		50		$(50/100)^4 = 0.0625$	4 606
3	(0.03*1800)/2.5= 21.6	50	7 884	$(50/100)^4 = 0.0625$	493
		110		$(110/100)^4 = 1.464$	11 543
		160		$(160/100)^4 = 6.554$	51 672
Σ					**69 174**

b) Calculate the *CGF* for the 15 years long Design Period:

Values of *CGF* are summarized in the table below:

Design period (P) (years)	Annual growth rate (R) (%)							
	0	1	2	3	4	6	8	10
5	5	5.1	5.2	5.3	5.4	5.6	5.9	6.1
10	10	10.5	10.9	11.5	12.0	13.2	14.5	15.9
15	15	16.1	17.3	18.6	20.0	23.3	27.2	31.8
20	20	22.0	24.3	26.9	29.8	36.8	45.8	57.3
25	25	28.2	32.0	36.5	41.6	54.9	73.1	98.3

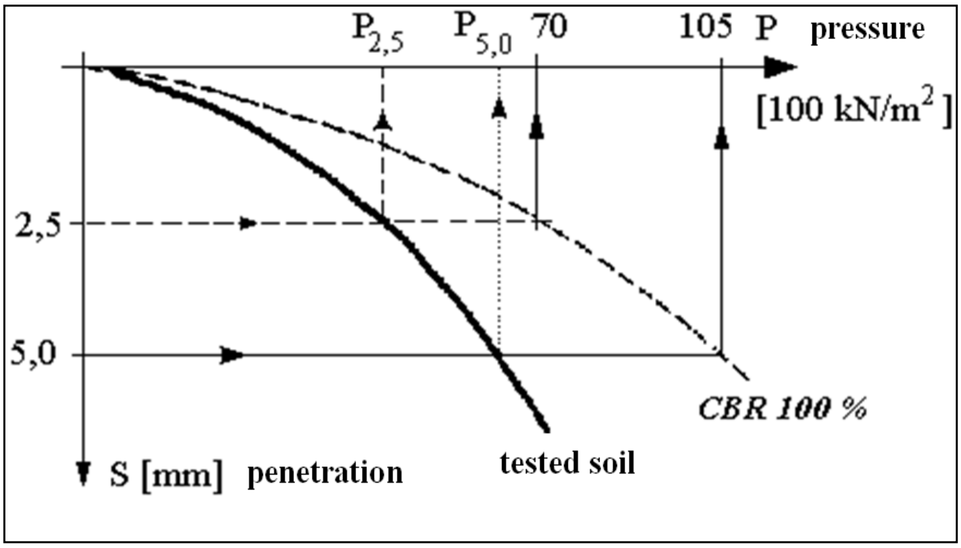
From the table *CGF* for P=15 years, when annual growth rate is R=2%, equals 17.3.
The assumed value of the Direction Factor is 0.5.
Thus the total ESAL during the design period is 0.5*17.3*69 174 = **598 355** = **0.6 msa**

3. Example

The following observations were recorded in a California Bearing Ratio – CBR test. Determine the CBR values and suitability of the soil intended to be used as sub-grade for a new road.

***S* penetration in mm**	0.0	0.5	1.0	1.5	2.0	3.0	4.0	10.0
***P* load on plunger (kN/m^2)**	0.0	1.34	2.98	3.81	4.24	4.89	5.31	6.48

Solution



Calculate pression at penetration 2.5 mm and 5.0 mm, respectively, assuming the linearity of load/penetration function between two recorded values following each other:

$P_{2.5}$ = 4.24 + (4.89-4.24)/2 = **4.565** kN
$P_{5.0}$ = 5.31+ (6.48-5.31)/6 = **5.505** kN

Values of CBR%:

CBR% = 100*($P_{2.5}$ / 70) = 100*(4.565/70) = **6.5%**
CBR% = 100*($P_{5.0}$ / 105) = 100*(5.505/105) = **5.2%**

The bigger value prevails, thus CBR% is 6.5%>5%, i.e. the subsoil is *suitable* for serving as a *subgrade* supporting a *flexible pavement*.

4. Example

Design the pavement for construction of a new bypass with the following data:

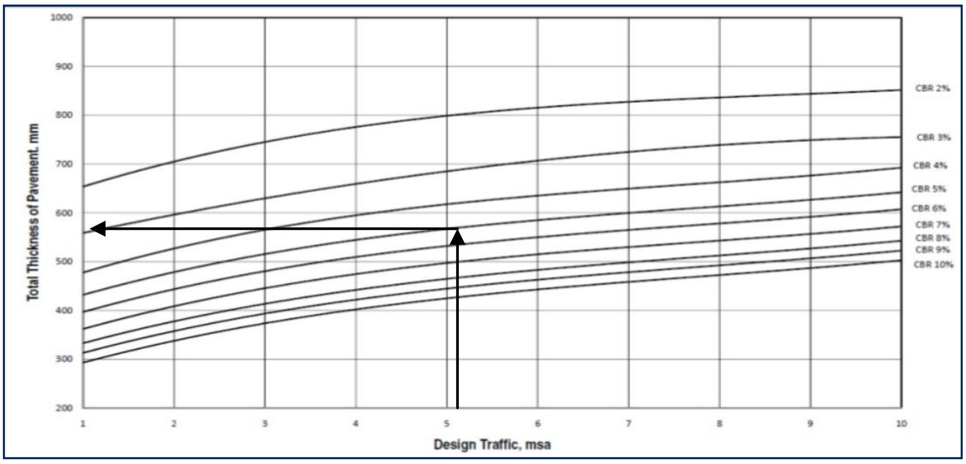
a) Two-lane carriageway (lane distribution factor LDF = 0.75)
b) Initial average traffic volume of Commercial Vehicles (CV) in the year of completion of construction (in both direction) AADT = 800 CVs/year
c) Traffic growth rate = 3%/year
d) Design life of pavement 15 years
e) Average damage factor based on axle load survey ADF = 2.5 ESAL/CV
f) Design CBR of sub-grade soil = 5%

Solution

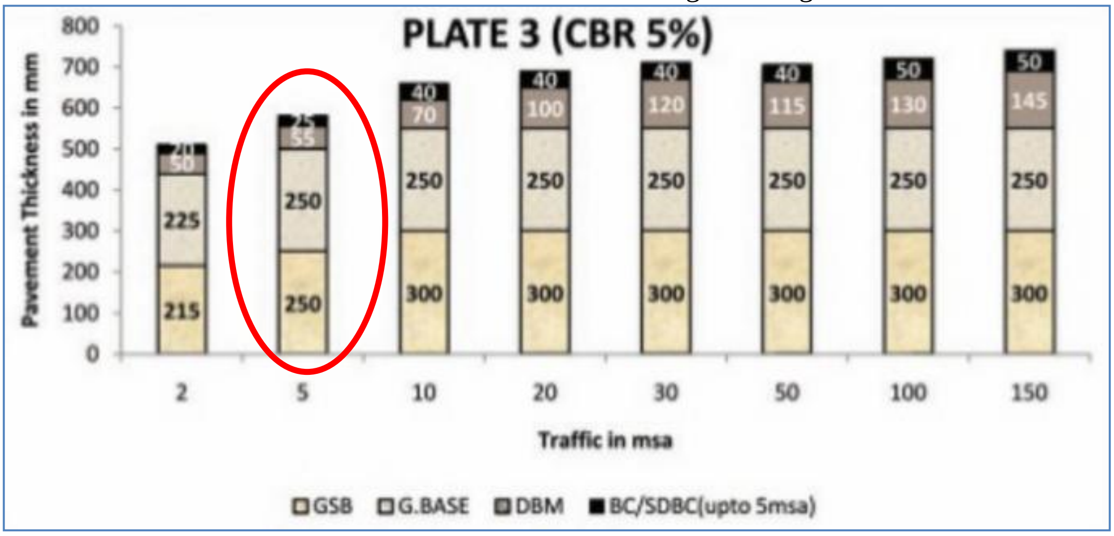
The value of CGF (given by the table in Example 2.) is 18.6
Calculate the design traffic:

$$T_{DT} = 365*AADT*CGF*DF*LDF*ADF$$
$$T_{DT} = 365*800*18.6*0.5*0.75*2.5 = \underline{\mathbf{5\,091\,750}} = \underline{\mathbf{5.1}} \text{ msa}$$

Total pavement thickness for CBR 5% and design traffic load 5.1 msa is **<u>580</u> mm** from the design chart below:



Pavement structure could be obtained from the Pavement Design Catalogue:



5. Example

A new road section is built to connect the old collector road to a new motorway interchange. The structure of the new road is:

40 mm HMA (Hot Mix Asphalt) as wearing course
100 mm DBM (Bituminous Macadam) as binder course
300 mm WMM (Wet Mix Macadam) as base course
250 mm GSB (Granular Sub-Base) as sub-base

The old roads' structure is:

40 mm HMA (Hot Mix Asphalt) as wearing course
100 mm BM (Bituminous Macadam) as binder course
250 mm WBM (Water Bound Macadam) as base course
250 mm GSB (Granular Sub-Base) as sub-base

The old pavement presumably needs to be strengthened by an overlay, because its condition is as follows:

GSB and WBM layers are in good condition **-** Conversion factor = 0.1
BM layer shows aggregate degradation **-** Conversion factor = 0.5
HMA layer shows appreciable cracking **-** Conversion factor = 0.6

Solution

Effective thickness of the old pavement:

$\boldsymbol{h_e}$ = 0.1*(250+250) + 0.5*100 + 0.6*40 = **<u>124</u>** mm

Equivalent thickness of new pavement in terms of AC

$\boldsymbol{h_n}$ = (300+250)×0.2 + (100+40)×1.0 = **<u>250</u>** mm

Thickness of *overlay*:

$h_{OL} = h_n - h_e$ = 250 – 124 = **<u>126</u>** mm

Provide **90 mm DBM** (Dense Bituminous Macadam) + **40 mm HMA** (Hot Mix Asphalt) as overlay

6. Example

Results of deflection measurements made on the surface of an existing two lane road with flexible pavement are as follows:

1.40;1.32;1.25; 1.35; 1.48; 1.60; 1.65; 1.55; 1.45; 1.40; 1.36; 1.46; 1.50; 1.52; 1.45 mm

The AADT (Annual Average Daily Traffic) of Heavy Vehicles = 1000 HV/day, with a forecast annual growth rate of R = 4%/year, while the average vehicle damage factor VDF = 4.5, and the design period is 10 years. Calculate the thickness of necessary *overlay* taking into account a seasonal correction factor of 1.4.

Solution

Calculate the *mean deflection*:

μ = (1.40+1.32+1.25+1.35+1.48+1.60+1.65+1.55+1.45+1.40+1.36+1.46+1.50+1.52+1.45)/15 = 21.74/15 = **1.45** mm

Calculate the *standard deviation*:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

Values of the *differences* between deflection values and mean deflection ($x_i - \mu$):

-0.05; -0.13; -0.2; -0.1; +0.03; +0.15; +0.2; +0.1; +0; -0.05; -0.09; +0.01; +0.05; +0.07; +0

Mean of the squares of these *differences*:
(0.0025+0.0169+0.04+0.01+0.0009+0.0225+0.04+0.01+0.0025+0.0081+0.0001+0.0025+0.0049)/15 =
= 0.1609/15= 0.0107266

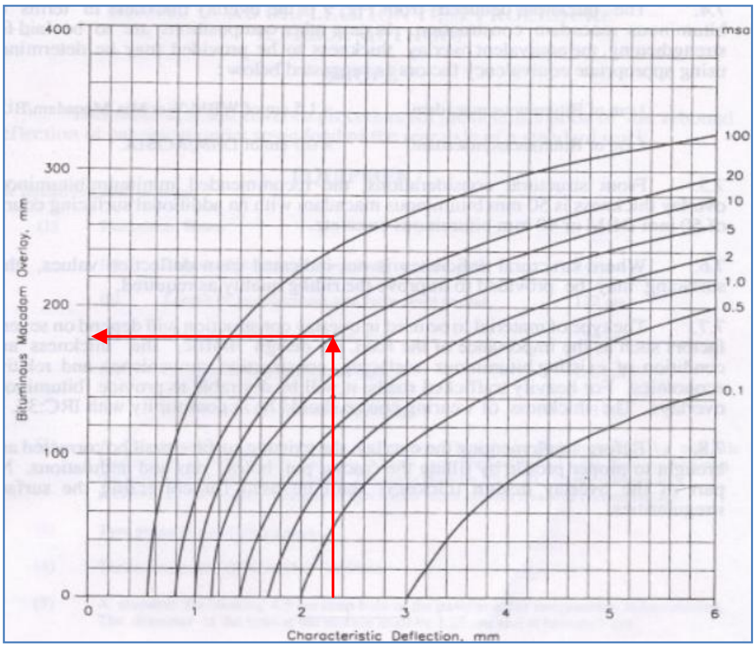
The standard deviation:
$\sigma = \sqrt{0.0107266}$ = **0.104** mm

Characteristic deflection: $\mu + 2*\sigma$ = 1.45 + 0.208 = **1.658** mm
Corrected characteristic deflection: 1.4*1.658 = **2.3212** mm

Calculate CGF = $[(1-0.01R)^{10} - 1]/0.01$ = **12.0**

Calculate the design traffic T_{DT} = 1000 * 365 * 12.0 * 4.5 * 0.5 = 9 855 000 = **9.86** msa

Define thickness of Bituminous Macadam (BM) overlay (mm) in function of characteristic deflection (mm) and design traffic (msa) from the standard chart below:



Thickness of overlay in terms of BM (Bituminous Macadam) from the chart = **180** mm

Thickness in terms of Bituminous Macadam / Hot Mix Asphalt: BM/HMA=180*0.7 = **126** mm

Provide **40** mm HMA and **90** mm DBM (Dense Bituminous Macadam) as overlays.