

# All Math Problems of

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ESAL - Equivalent Single Axle Load

LEF - Load Equivalency Factor

Load Equivalency:

Generalised fourth power approximation

$$\text{Relative damage factor} = \left( \frac{\text{load}}{18000 \text{ lb}} \right)^4$$

# Problem 1

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LEF example

## LEF Example

The standard axle weights for a standing-room-only loaded Metro articulated bus (60 ft. Flyer) are:

Axle	Empty	Full
Steering	13,000 lb.	17,000 lb.
Middle	15,000 lb.	20,000 lb.
Rear	9,000 lb.	14,000 lb.

Using the 4<sup>th</sup> power approximation, determine the total equivalent damage caused by this bus in terms of ESALs when it is empty. How about when it is full?



When empty:

$$\text{Total ESAL's} = \left(\frac{13000}{18000}\right)^4 + \left(\frac{15000}{18000}\right)^4 + \left(\frac{9000}{18000}\right)^4 = 0.817$$

When full:

$$\text{Total ESAL's} = \left(\frac{17000}{18000}\right)^4 + \left(\frac{20000}{18000}\right)^4 + \left(\frac{14000}{18000}\right)^4 = 2.686$$

per day total

$$ESAL = NXF = \text{No. of axles} \times \text{Equivalency factor}$$

$$\text{Base year ESAL} = \text{per day total ESAL} \times 365 \times \\ \text{Directional distribution} \times \\ \text{Lane distribution}$$

$$\text{Design ESAL} = \left\{ \frac{(1+g)^n - 1}{g} \right\} \times \text{Base year ESAL}$$

$g = \% \text{ growth}$

$n = \text{design year}$

## Problem-2

Pg-96

### Design Example - Part 1

Worksheet for Calculating Design 18-kip ESAL

Q Determine ESAL for the following axle load distribution survey data:

Highway type = 4 lane rural highway

Design year = 20 year

Uniform growth rate = 6%

Total no. of trucks weighed = 1000 (one day & both directions)

Assume,

Terminal Serviceability,  $P_t = 2.5$

Structural number,  $SN = 6.0$

Axle Load Groups (kip)	midpoint	Number of Axles, N	Equivalency Factor, F	ESAL N x F
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Single Axle :

Table 1

0-3	1.5	0	0.0002	0
3-7	5	8	0.0055	0.044
7-8	7.5	400	0.0255	10.2
8-12	10	1200	0.08	96
12-15	13.5	425	0.30025	127.61
26-30	28	375	5.98	2242.5

Tandem Axle

Table-2

0-6	3	0	0.001	0
6-12	9	23	0.0045	0.1035
12-18	15	167	0.0335	5.5945
18-24	21	400	0.138	55.2
24-30	27	287	0.411	117.957
30-32	31	450	0.7335	330.075
32-34	33	460	0.957	440.22
34-36	35	453	1.23	557.19

18 kip EAL's for all trucks weighed = 3982.694

**Table 1 Axle Load Equivalency Factors for Flexible Pavements**  
**Single Axles (Pt = 2.5)**

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002
4	0.003	0.004	0.004	0.003	0.002	0.002
6	0.011	0.017	0.017	0.013	0.01	0.009
8	0.032	0.047	0.051	0.041	0.034	0.031
10	0.078	0.102	0.118	0.102	0.088	0.08
12	0.168	0.198	0.229	0.213	0.189	0.175
14	0.328	0.358	0.399	0.388	0.36	0.342
16	0.591	0.613	0.656	0.645	0.623	0.606
18	1	1	1	1	1	1
20	1.61	1.57	1.49	1.47	1.51	1.55
22	2.48	2.38	2.17	2.09	2.18	2.3
24	3.69	3.49	3.09	2.89	3.03	3.27
26	5.33	4.99	4.31	3.91	4.09	4.48
28	7.49	6.98	5.9	5.21	5.39	5.98
30	10.3	9.5	7.9	6.8	7	7.8
32	13.9	12.8	10.5	8.8	8.9	10
34	18.4	16.9	13.7	11.3	11.2	12.5
36	24	22	17.7	14.4	13.9	15.5
38	30.9	28.3	22.6	18.1	17.2	19
40	39.3	35.9	28.5	22.5	21.1	23
42	49.3	45	35.6	27.8	25.6	27.7
44	61.3	55.9	44	34	31	33.1
46	75.5	68.8	54	41.4	37.2	39.3
48	92.2	83.9	65.7	50.1	44.5	46.5
50	112	102	79	60	53	55

**Lane distribution factors**

Number of lanes in both directions	Percent of 18-kip ESAL traffic in design lane
1	100
2	80 - 100
3	60 - 80
4 or more	50 - 75

≈ 90

**Table 2 Axle Load Equivalency Factors for Flexible Pavements**  
**Tandem Axles (Pt = 2.5)**

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	0.0001	0.0001	0.0001	0	0	0
4	0.0005	0.0005	0.0004	0.0003	0.0003	0.002
6	0.002	0.002	0.002	0.001	0.001	0.001
8	0.004	0.006	0.005	0.004	0.003	0.003
10	0.008	0.013	0.011	0.009	0.007	0.006
12	0.015	0.024	0.023	0.018	0.014	0.013
14	0.026	0.041	0.042	0.033	0.027	0.024
16	0.044	0.065	0.08	0.057	0.017	0.043
18	0.07	0.097	0.109	0.092	0.077	0.07
20	0.107	0.141	0.162	0.141	0.121	0.11
22	0.16	0.198	0.669	0.207	0.18	0.166
24	0.231	0.273	0.315	0.282	0.26	0.242
26	0.327	0.37	0.42	0.401	0.364	0.342
28	0.451	0.493	0.548	0.534	0.495	0.48
30	0.611	0.648	0.703	0.695	0.658	0.633
32	0.813	0.843	0.889	0.887	0.857	0.834
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.7	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14
42	2.76	2.67	2.49	2.43	2.51	2.61
44	3.41	3.27	2.99	2.88	3	3.16
46	4.18	3.98	3.58	3.4	3.55	3.79
48	5.08	4.8	4.25	3.98	4.17	4.49
50	6.12	5.76	5.03	4.64	4.86	5.28
52	7.33	6.87	5.93	5.38	5.63	6.17
54	8.72	8.14	6.95	6.22	6.47	7.15
56	10.3	9.6	8.1	7.2	7.4	8.2
58	12.1	11.3	9.4	8.2	8.4	9.4
60	14.2	13.1	10.9	9.4	9.6	10.7
62	16.5	15.3	12.6	10.7	10.8	12.1
64	19.1	17.6	14.5	12.2	12.2	13.7
66	22.1	20.3	16.6	13.8	13.7	15.4
68	25.3	23.3	18.9	15.6	15.4	17.2
70	29	26.6	21.5	17.6	17.2	19.2
72	33	30.3	24.4	19.8	19.2	21.3
74	37.5	34.4	27.6	22.2	21.3	23.6
76	42.5	38.9	31.1	24.8	23.7	26.1
78	48	43.9	35	27.8	26.2	28.8
80	54	49.4	39.2	30.9	29	31.7
82	60.6	55.4	43.9	34.4	32	34.8
84	67.8	61.9	49	38.2	35.3	38.1
86	75.7	69.1	54.5	42.3	38.8	41.7
88	84.3	76.9	60.6	46.8	42.6	45.6
90	93.7	85.4	67.1	51.7	46.8	49.7

$$\text{Per day total ESAL} = 3983$$

$$\text{Directional distribution} = 0.50$$

(as AADT is counted for both directions)

$$\text{Lane distributions} = 0.90$$

(table-1)

$$\begin{aligned} \text{Base year ESAL} &= 365 \times 3982.694 \times 0.50 \times 0.90 \\ &= 654157.4895 \end{aligned}$$

$$\text{Design ESAL} = \left\{ \frac{(1+g)^n - 1}{g} \right\} \times \text{Base year ESAL}$$

$$= \left\{ \frac{(1+0.06)^{20} - 1}{0.06} \right\} \times 654157.4895$$

$$= 24063570$$

$$= 24 \text{ million}$$

From Nomograph,

$$\text{SN for design ESAL} = 5.71$$

??

which is equal to the assumed value,  
and no further trial is needed.

A = Base year annual average daily traffic in both directions

B = Growth factor for each type of vehicle

assuming annual compounded rate of growth factor

$$= \frac{(1+g)^n - 1}{g}$$

where  $g = \% \text{ growth}$   
 $n = \text{design year}$

C = Forecasted traffic =  $A \times B \times 365$

D = Equivalent single axle factors for assumed SN/D & P<sub>f</sub>

E = C x D

Design ESAL = Total Forecasted ESAL (E) x Directional distribution x Lane distribution

Problem-3

Pg-97

Worksheet for calculating Design 18 kip-ESAL

Q Determine ESAL for the following road survey data

Highway type = 4 lane rural highway

Design year = 20

Average daily Traffic = 10034 (both direction)

Assumed, SN or D = 6

$P_t = 2.5$

?? given

Vehicle Types	Current AADT (A)	Growth rate (g)	Growth Factor (B)	Forecasted Traffic (C)	ESAL Factor (D)	Forecasted ESAL (E)
			$\frac{(1+g)^n - 1}{g}$	$A \times B \times 365$		$C \times D$
Passenger Car	5925	2%	24.3	52551788	0.0008	42042
Small Buses	235		24.3	2084333	0.0081	16883
Large Buses	450	2%	24.3	3991275	0.6806	2716462
Pickup Trucks	1135		29.78	12337110	0.0122	150513
2 axle/6 tire trucks	375	4%	29.78	4076138	0.6560	2673947
3 or more axle trucks	34		29.78	369570	0.8646	319530
5 or more axle trailers	1880	4%	29.78	20435036	2.3719	48469862
	$\Sigma = 10034$					$\Sigma = 54389239$

Directional Distribution = 0.5

(as AADT is counted for both directions)

Lane distribution = 0.90

(from table 1)

$$\begin{aligned} \text{Design ESAL} &= 54389239 \times 0.5 \times 0.90 \\ &= 24475158 = 24.5 \text{ million} \end{aligned}$$

From

SN for design ESAL

??

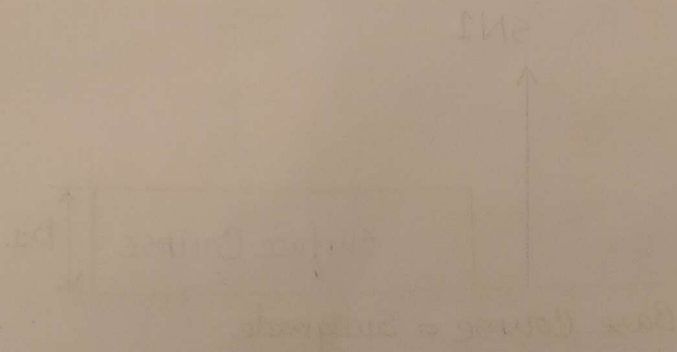
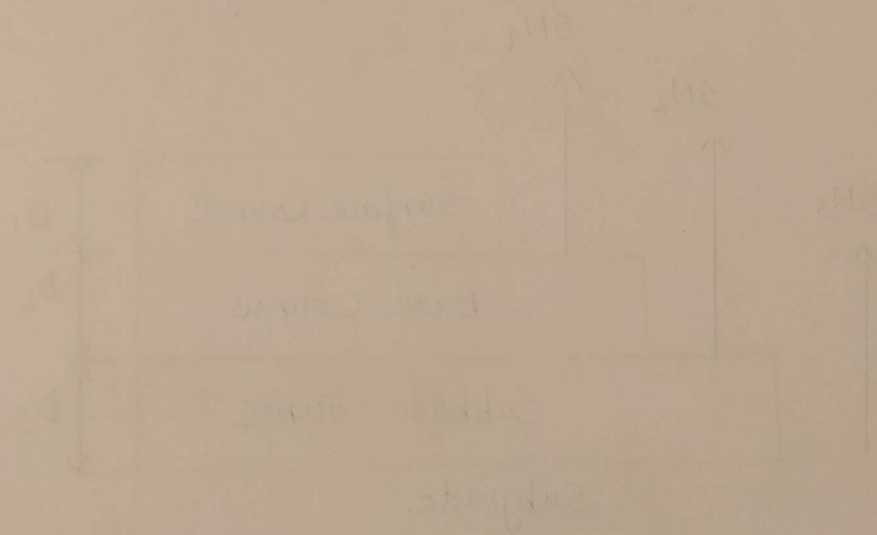
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which is equal to the assumed value and as such no further trial is needed

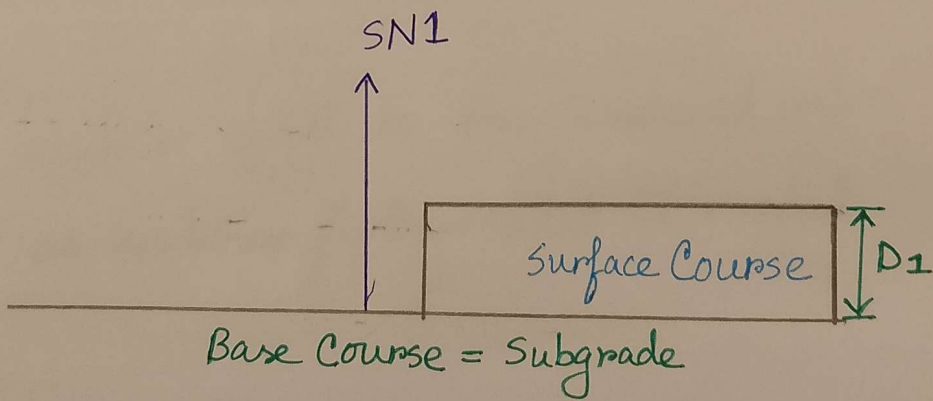
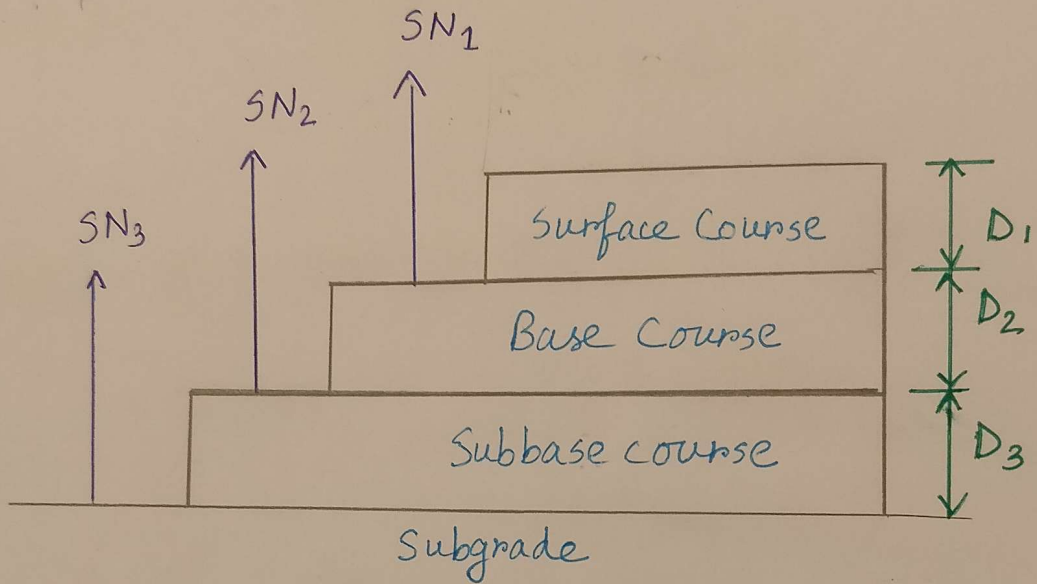
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# Flexible Pavement Design

## AASHTO Method



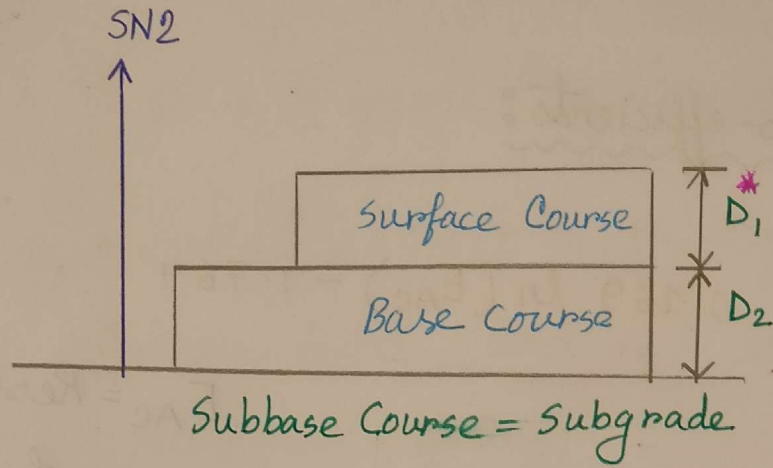
$$SNI_1 > SNI_2 > SNI_3$$
$$SNI_1 = \frac{E_1 D_1}{E_2 D_2}$$



$$a_1 D_1^* \geq SN_1$$

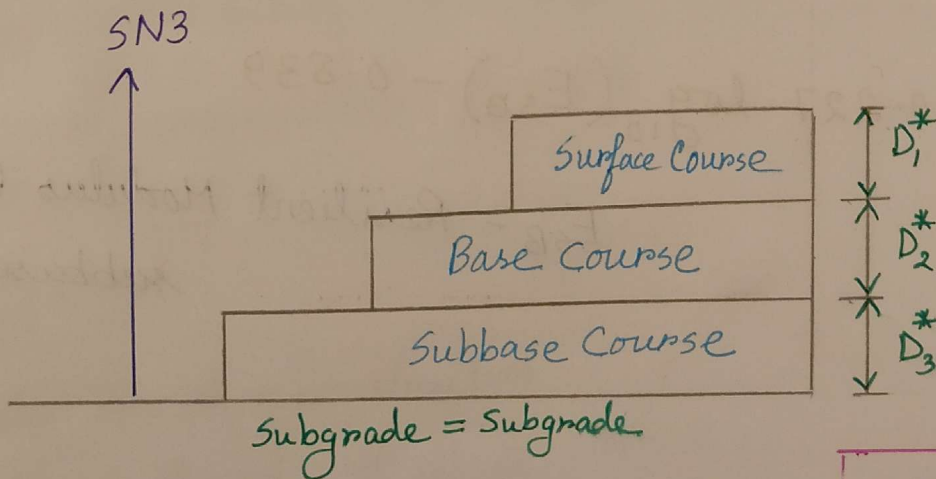
$$D_1^* \geq \frac{SN_1}{a_1}$$

$D_1^*$  → rounded to nearest  $\frac{1}{2}$  inch thickness



$$a_1 D_1^* + a_2 D_2^* \geq SN2$$

$$D_2^* \geq \frac{SN2 - a_1 D_1^*}{a_2}$$



$$a_1 D_1^* + a_2 D_2^* + a_3 D_3^* \geq SN3$$

$$D_3^* \geq \frac{SN3 - a_1 D_1^* - a_2 D_2^*}{a_3}$$

# If drainage co-eff is given (m) it will be multiplied with  $a$

## Layer Co-efficients:

$$a_1 = 0.169 \ln(E_{AC}) - 1.764$$

$E_{AC}$  = Resilient Modulus ( $M_R$ )  
of asphalt concrete  
(psi)

$$a_2 = 0.249 \log_{10}(E_{BS}) - 0.971$$

$E_{BS}$  = Resilient Modulus ( $M_R$ ) of  
base course (psi)

$$a_3 = 0.227 \log_{10}(E_{SB}) - 0.839$$

$E_{SB}$  = Resilient Modulus ( $M_R$ ) of  
subbase course (psi)

## Problem-4

Pg-98

### Design of Flexible Pavement using AASHTO Method

Q Design a flexible pavement by AASHTO method for the given data below. Give one trial and put your comments for the next trial thickness (if any)

Traffic Data:

Estimated design ESAL = 23.3 million

Overall growth factor = 6.0

Soil Characteristics:

(not needed for this math)

Pavement Data:

Initial Serviceability,  $P_0 = 4.6$

Terminal Serviceability,  $P_t = 2.5$

Design Strategy:

Consider two stage construction

Design Period = 20 years

Initial service life of the pavement = 15 years

### Statistical data:

Reliability for each stage,  $R = 0.95$

(Assume) Overall standard deviation,  $S_0 = 0.35$

$$Z_R = -1.645$$

Pavement Layer	Material Used	Resilient Modulus $M_n$ (psi)	Layer Coefficients	Drainage Coefficients
Surface Course (AC)	Asphalt Concrete	$E_{AC} = 400,000$	$a_1 = 0.169 \cdot \ln(E_{AC}) - 1.764$	$m_1 = 1.0$
Base Course (BS)	Granular	$E_{BS} = 30,000$	$a_2 = 0.249 \cdot \log_{10}(E_{BS}) - 0.977$	$m_2 = 1.2$
Subbase Course (SB)	Granular	$E_{SB} = 11,000$	$a_3 = 0.227 \cdot \log_{10}(E_{SB}) - 0.839$	$m_3 = 1.2$
Roadbed Course (RB)	Compacted soil	$E_{RB} = 5,700$		

Note: 1. Assume reasonable values for missing data, if any.

2. Write the results in the AASHTO worksheet provided.

3. AASHTO Design Nomograph for flexible pavement is also provided.

### Solution:

Surface Course:  $D_1 = \frac{SN_1}{a_1 m_1}$

$$SN_1^* = a_1 D_1^* m_1$$

Base Course:  $D_2 = \frac{SN_2 - SN_1^*}{a_2 m_2}$

$$SN_2^* = a_2 m_2 D_2^*$$

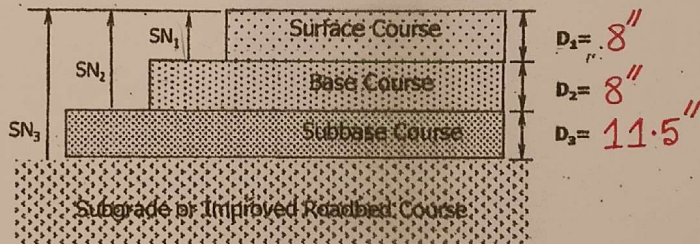
Subbase Course:  $D_3 = \frac{SN_3 - SN_2^* - SN_1^*}{a_3 m_3}$

Check for  $SN_3 = a_1 m_1 D_1^* + a_2 m_2 D_2^* + a_3 m_3 D_3^*$

**AASHTO Worksheet For Flexible Pavement Design**

Pavement Layer	Material Used	Resilient Modulus $M_R$ (psi)		Layer Coefficients		Drainage Coefficient	Required SN above the layer	Calculations For Layer Thicknesses		Thickness D (inch)
		$E_{R0}$	$M_R$	$a_i = 0.169 \cdot \ln(E_{RC}) - 1.764$	$m_i$					
Surface Course	Asphalt Concrete	$E_{R0} =$	400,000	$a_1 = 0.169 \cdot \ln(E_{RC}) - 1.764 =$	0.42	$m_1 =$	1.0	$D_1 = SN_1 / a_1 m_1 = 7.86$ $SN_1^* = a_1 D_1^* m_1 = 3.36$		8.0 ← $D_1^*$
Base Course	Granular	$E_{RS} =$	30,000	$a_2 = 0.249 \cdot \log_{10}(E_{RS}) - 0.977 =$	0.14	$m_2 =$	1.2	$SN_1 = 3.3$ $D_2 = (SN_2 - SN_1^*) / a_2 m_2 = 7.98$ $SN_2^* = a_2 m_2 D_2^* = 1.344$		8.0 ← $D_2^*$
Subbase Course	Granular	$E_{RS} =$	11,000	$a_3 = 0.227 \cdot \log_{10}(E_{RS}) - 0.839 =$	0.08	$m_3 =$	1.2	$SN_2 = 4.7$ $D_3 = (SN_3 - SN_2^* - SN_1^*) / a_3 m_3 = 11.42$		11.5 ← $D_3^*$
Roadbed Course	Compacted soil	$E_{RB} =$	5,700					$SN_3 = 5.8$		

Check for  $SN_3 = a_1 m_1 D_1 + a_2 m_2 D_2 + a_3 m_3 D_3 = 0.42 \times 1 \times 8 + 0.14 \times 1.2 \times 8 + 0.08 \times 1.2 \times 11.5 = 5.8$



$SN_1$ : Reliability 95%,  $S_o = 0.35$ ,  $W_{18} = 23.3$  million,  $E_{BS} = M_R = 30000$  psi,

$\Delta PSI = P_o - P_t = 2.1$

From Nomograph  $\rightarrow SN_1 = 3.3$

$SN_2$ :  $E_{SB} = M_R = 11000$  psi = 11 ksi

From Nomograph  $\rightarrow SN_2 = 4.7$

$SN_3$ :  $E_{RB} = M_R = 5700$  psi = 5.7 ksi

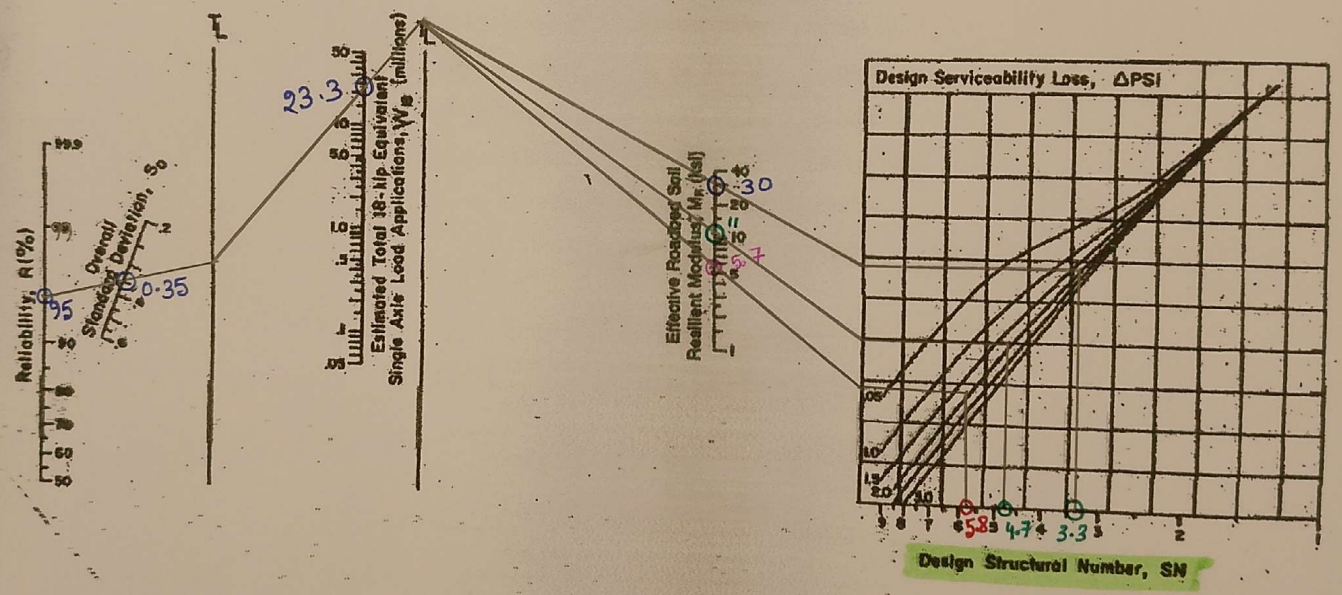
From Nomograph  $\rightarrow SN_3 = 5.8$

[next page - nomograph]

### AASHTO Design Nomograph for Flexible Pavement

NOMOGRAPH SOLVES:

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



## Rigid Pavement

### PCA Thickness Design Method

#### Design Parameters :

- 1) Concrete modulus of rupture (MR)
- 2) Modulus of subgrade reaction (k) [psi/inch]
- 3) Design traffic volume
- 4) Axle load spectrum

#### Design Traffic Volume ,

$$V = 365 (ADT) (T) (D) (L) (G) (Y)$$

ADT = Average Daily Traffic (two-way)

T = Percent trucks

D = Direction distribution factor

L = Lane distribution factor

(from graph using (ADT)(D)(G) & lane no.)

G = Traffic Growth multiplier =  $(1+r)^{Y/2}$   
r = annual growth rate

Y = Design life

Problem-5

Pg-104

Q Determine the design traffic volume for a four-lane rural highway having the following conditions:

$$ADT = 12900 \text{ (two-way)}$$

$$\text{Truck percentage} = T = 19\%$$

$$\text{Growth factor, } r = 4\%$$

$$\text{Design life, } Y = 20 \text{ years}$$

$$\text{Directional distribution, } D = 0.50 \text{ (assumed)}$$

Design traffic volume,

$$V = 365 (ADT) (T) (D) (L) (G) (Y)$$

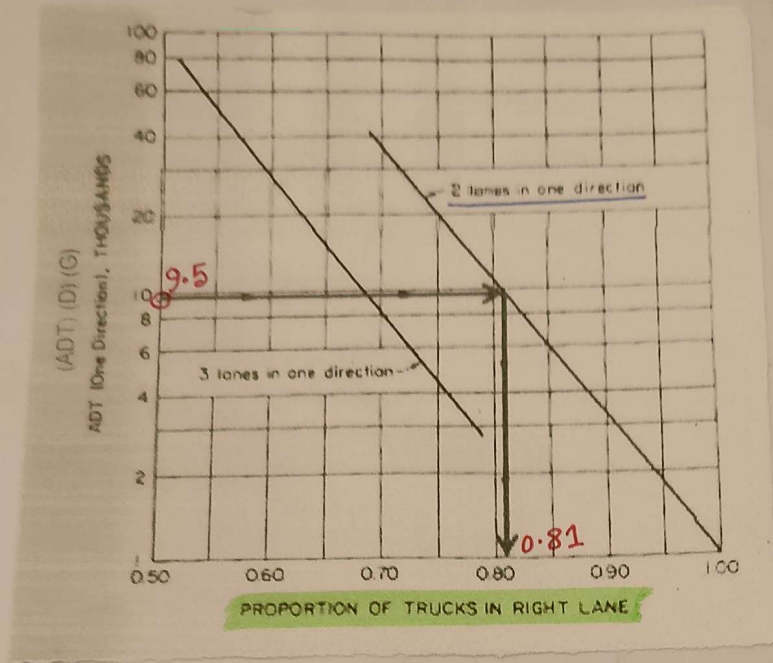
Traffic growth multiplier,

$$G = (1+r)^{Y/2} = (1+0.04)^{20/2} = 1.48$$

For lane distribution factor:

$$(ADT) (D) (G) = 12900 \times 0.5 \times 1.48 = 9546$$

2 lanes in one direction



∴ Lane distribution factor,

$$L = 0.81$$

Now,  $V = 365 (ADT) (T) (D) (L) (G) (Y)$

$$= 365 (12900) (0.19) (0.5) (0.81) (1.48) (20)$$

$$V = 10730000 \text{ trucks}$$

Ans

## PCA method Design Details

Based on *Miner's Hypothesis*,

$$D = \sum_i \frac{n_i}{N_i} \leq 1$$

$D$  = Pavement life consumed by axle loads

$n_i$  = actual number of axle loads in class  $i$

$N_i$  = axle loads needed to produce failure

### Design procedure

1) Choose a trial slab thickness ( $h$ )

2) For each axle load class:

a) Determine  $N_i$  for fatigue failure

b) Divide  $n_i$  by  $N_i$  to determine fatigue damage factor  $d_i$

c) Determine  $N_i$  for erosion failure

d) Divide  $n_i$  by  $N_i$  to determine

erosion damage factor  $d_i$

3) Sum fatigue and erosion damage factors over all of the axle load classes.

4) If both sums are less than 1 (life),

design is good,

otherwise slab thickness should be increased.

Problem-6

Pg-108

Q Design a concrete pavement by using **PCA method** for the conditions given below.  
Give one trial and put your comments on the trial thickness.

Traffic (ADT) = 12900 (two way)

Trucks = 19%

Annual growth = 4%

Modulus of Rupture,  $M_R = 650 \text{ psi}$

Modulus of Subgrade reaction,  $k = 100 \text{ psi/in} = 100 \text{ pci}$

Design life = 20 years

Doweled joint = Yes

Asphalt Shoulder = Yes

Subbase = 4 inch (untreated)

Let us assume, a trial thickness = 9.5 inch

Modulus of Subgrade Reaction

Design k Values for Untreated Subbases

Subgrade k value, pci	Subbase k value, pci			
	4 in.	6 in.	9 in.	12 in.
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430

Design k Values for Cement-Treated Subbases

Subgrade k value, pci	Subbase k value, pci			
	4 in.	6 in.	8 in.	10 in.
50	170	230	310	390
100	280	400	520	640
200	470	640	830	—

For

subgrade  $k = 100$  pci

&

4" untreated subbase

subbase-subgrade  $k$

= 130 pci

Load Safety Factor (Multiplication factor for axle loads)

Traffic Volume	LSF
High (interstates, multilane highways)	1.2
Moderate (highways and arterials)	1.1
Low (collectors, residential streets)	1.0

For interstates, multilane highways,

Load safety factor,  $LSF = 1.2$

There is doweled joint and no concrete shoulder.

**Equivalent Stress - No Concrete Shoulder (Single Axle / Tandem Axle)**

**Equivalent Stress - Concrete Shoulder (Single Axle / Tandem Axle)**

$k$  of subgrade-subbase, pci = 130 pci

Slab thickness, in.	$k$ of subgrade-subbase, pci						
	50	100	150	200	300	500	700
4	825/679	726/585	671/542	634/516	584/486	523/457	484/443
4.5	699/586	616/500	571/460	540/435	499/406	448/378	417/363
5	622/516	537/436	493/399	467/378	432/348	389/324	363/307
5.5	526/441	454/387	421/353	406/331	379/305	343/275	320/264
6	455/416	411/348	382/316	362/286	336/271	304/246	285/232
6.5	417/380	367/317	341/286	324/267	300/244	273/220	256/207
7	375/349	331/290	307/262	292/244	271/222	246/199	231/186
7.5	340/323	300/268	279/241	265/224	246/203	224/181	210/169
8	311/300	274/249	255/223	243/206	225/185	205/167	192/159
8.5	285/251	252/232	234/208	222/193	206/174	188/154	177/145
9	264/264	232/218	216/195	205/181	190/163	174/144	163/133
9.5	245/248	215/205	200/183	190/170	176/153	161/134	151/124
10	228/235	200/193	186/173	177/160	164/144	150/126	141/117
10.5	213/222	187/183	174/164	165/151	153/136	140/119	132/110
11	200/211	175/174	163/155	154/143	144/129	131/113	123/104
11.5	188/201	165/165	153/148	145/136	135/122	123/107	116/98
12	177/192	155/158	144/141	137/130	127/116	116/102	109/93
12.5	166/183	147/151	136/135	129/124	120/111	109/97	103/89
13	159/176	139/144	129/129	122/119	113/106	103/93	97/85
13.5	152/168	132/138	122/123	116/114	107/102	96/89	92/81
14	144/162	125/133	116/118	110/109	102/98	93/85	86/78

Slab thickness, in.	$k$ of subgrade-subbase, pci						
	50	100	150	200	300	500	700
4	640/534	559/468	517/439	489/422	452/403	409/368	383/384
4.5	547/461	479/400	444/372	421/356	390/338	355/322	333/316
5	475/404	417/349	387/323	367/308	341/290	311/274	294/267
5.5	416/360	358/309	342/285	324/271	302/254	276/238	261/231
6	372/325	327/277	304/255	289/241	270/225	247/210	234/203
6.5	334/296	294/253	274/230	260/218	243/203	223/188	212/180
7	302/270	266/230	246/210	236/198	220/184	203/170	192/162
7.5	275/250	243/211	226/193	215/182	201/168	185/155	176/148
8	252/232	222/196	207/179	197/168	185/155	170/142	162/135
8.5	232/216	205/182	191/165	182/156	170/144	157/131	150/125
9	215/202	190/171	177/156	169/146	158/134	146/122	139/118
9.5	200/190	176/160	164/146	157/137	147/126	136/114	129/108
10	186/179	164/151	153/137	146/129	137/118	127/107	121/101
10.5	174/170	154/143	144/130	137/121	120/111	119/101	113/95
11	164/161	144/135	135/123	129/115	120/105	112/95	106/90
11.5	154/153	136/128	127/117	121/109	113/100	105/90	100/86
12	145/146	128/122	120/111	114/104	107/95	99/86	95/81
12.5	137/139	121/117	113/106	108/99	101/91	94/82	90/77
13	130/133	115/112	107/101	102/95	96/86	89/78	85/73
13.5	124/127	109/107	102/97	97/91	91/83	85/74	81/70
14	118/122	104/103	97/93	93/87	87/79	81/71	77/67

Single axle:

For slab thickness = 9.5 inch

&  $k$  for subgrade-subbase = 130 pci

• Equivalent stress =  $215 - \frac{15}{50} \times 30 = 206$

• Stress ratio factor =  $\frac{\text{Equivalent stress}}{MR}$

=  $\frac{206}{650}$

= 0.317

Tandem axle:

- Equivalent stress =  $205 - \frac{22}{50} \times 30 = 191.8 = 192$
- Stress ratio factor =  $\frac{192}{650} = 0.295$

Erosion Factor

Erosion Factor - Doweled Joints, Concrete Shoulder (Single Axle / Tandem Axle)

Slab thickness, in.	k of subgrade-subbase, pci					
	50	100	200	300	500	700
4	3.28/3.30	3.24/3.20	3.21/3.13	3.19/3.10	3.15/3.09	3.12/3.08
4.5	3.13/3.19	3.05/3.08	3.06/3.00	3.04/2.96	3.01/2.93	2.98/2.91
5	3.01/3.09	2.97/2.98	2.93/2.89	2.90/2.84	2.87/2.79	2.85/2.77
5.5	2.90/3.01	2.85/2.89	2.81/2.79	2.79/2.74	2.76/2.68	2.73/2.65
6	2.79/2.93	2.75/2.82	2.70/2.71	2.68/2.65	2.65/2.58	2.62/2.54
6.5	2.70/2.86	2.65/2.75	2.61/2.63	2.58/2.57	2.55/2.50	2.52/2.45
7	2.61/2.79	2.56/2.68	2.52/2.56	2.49/2.50	2.46/2.42	2.43/2.38
7.5	2.53/2.73	2.48/2.62	2.44/2.50	2.41/2.44	2.38/2.36	2.35/2.31
8	2.46/2.68	2.41/2.56	2.36/2.44	2.33/2.38	2.30/2.30	2.27/2.24
8.5	2.39/2.62	2.34/2.51	2.29/2.39	2.26/2.32	2.22/2.24	2.20/2.18
9	2.32/2.57	2.27/2.46	2.22/2.34	2.19/2.27	2.16/2.19	2.13/2.13
9.5	2.26/2.52	2.21/2.41	2.16/2.29	2.13/2.22	2.09/2.14	2.07/2.08
10	2.20/2.47	2.15/2.36	2.10/2.25	2.07/2.18	2.03/2.09	2.01/2.03
10.5	2.15/2.43	2.09/2.32	2.04/2.20	2.01/2.14	1.97/2.05	1.95/1.99
11	2.10/2.39	2.04/2.28	1.99/2.16	1.95/2.09	1.92/2.01	1.89/1.95
11.5	2.05/2.35	1.99/2.24	1.93/2.12	1.90/2.05	1.87/1.97	1.84/1.91
12	2.00/2.31	1.94/2.20	1.88/2.09	1.85/2.02	1.82/1.93	1.79/1.87
12.5	1.95/2.27	1.89/2.16	1.84/2.05	1.81/1.98	1.77/1.89	1.74/1.84
13	1.91/2.23	1.85/2.13	1.79/2.01	1.76/1.95	1.72/1.86	1.70/1.80
13.5	1.86/2.20	1.81/2.09	1.75/1.98	1.72/1.91	1.68/1.83	1.65/1.77
14	1.82/2.17	1.76/2.06	1.71/1.95	1.67/1.88	1.64/1.80	1.61/1.74

Erosion Factor - No Dowels, Concrete Shoulder (Single Axle / Tandem Axle)

Slab thickness, in.	k of subgrade-subbase, pci					
	50	100	200	300	500	700
4	3.46/3.49	3.42/3.39	3.38/3.32	3.36/3.29	3.32/3.26	3.28/3.24
4.5	3.32/3.39	3.28/3.28	3.24/3.19	3.22/3.16	3.19/3.12	3.15/3.09
5	3.20/3.30	3.16/3.18	3.12/3.09	3.10/3.05	3.07/3.00	3.04/2.97
5.5	3.10/3.22	3.05/3.10	3.01/3.00	2.99/2.95	2.96/2.90	2.93/2.86
6	3.00/3.15	2.95/3.02	2.90/2.92	2.88/2.87	2.85/2.81	2.83/2.77
6.5	2.91/3.08	2.86/2.96	2.81/2.85	2.79/2.79	2.76/2.73	2.74/2.68
7	2.83/3.02	2.77/2.90	2.73/2.78	2.70/2.72	2.68/2.66	2.65/2.61
7.5	2.76/2.97	2.70/2.84	2.65/2.72	2.62/2.66	2.60/2.59	2.57/2.54
8	2.69/2.92	2.63/2.79	2.57/2.67	2.55/2.61	2.52/2.53	2.50/2.48
8.5	2.63/2.88	2.56/2.74	2.51/2.62	2.48/2.55	2.45/2.48	2.43/2.43
9	2.57/2.83	2.50/2.70	2.44/2.57	2.42/2.51	2.39/2.43	2.36/2.38
9.5	2.51/2.79	2.44/2.65	2.38/2.53	2.36/2.46	2.33/2.38	2.30/2.33
10	2.46/2.75	2.39/2.61	2.33/2.49	2.30/2.42	2.27/2.34	2.24/2.28
10.5	2.41/2.72	2.33/2.58	2.27/2.45	2.24/2.38	2.21/2.30	2.19/2.24
11	2.36/2.68	2.28/2.54	2.22/2.41	2.19/2.34	2.16/2.26	2.14/2.20
11.5	2.32/2.65	2.24/2.51	2.17/2.38	2.14/2.31	2.11/2.22	2.09/2.16
12	2.28/2.62	2.19/2.48	2.13/2.34	2.10/2.27	2.06/2.19	2.04/2.13
12.5	2.24/2.59	2.15/2.45	2.09/2.31	2.05/2.24	2.02/2.15	1.99/2.10
13	2.20/2.56	2.11/2.42	2.04/2.28	2.01/2.21	1.98/2.12	1.95/2.08
13.5	2.16/2.53	2.08/2.39	2.00/2.25	1.97/2.18	1.93/2.09	1.91/2.03
14	2.13/2.51	2.04/2.36	1.97/2.23	1.93/2.15	1.89/2.06	1.87/2.00

Erosion Factor - Doweled Joints, No Concrete Shoulder (Single Axle / Tandem Axle)

Slab thickness, in.	k of subgrade-subbase, pci = 130 pci					
	50	100	200	300	500	700
4	3.74/3.83	3.73/3.79	3.72/3.75	3.71/3.73	3.70/3.70	3.68/3.67
4.5	3.59/3.70	3.57/3.65	3.56/3.61	3.55/3.58	3.54/3.55	3.52/3.53
5	3.45/3.58	3.43/3.52	3.42/3.48	3.41/3.45	3.40/3.42	3.38/3.40
5.5	3.33/3.47	3.31/3.41	3.29/3.36	3.28/3.33	3.27/3.30	3.26/3.28
6	3.22/3.38	3.19/3.31	3.18/3.26	3.17/3.23	3.15/3.20	3.14/3.17
6.5	3.11/3.29	3.09/3.22	3.07/3.16	3.05/3.13	3.05/3.10	3.03/3.07
7	3.02/3.21	2.99/3.14	2.97/3.08	2.95/3.05	2.95/3.01	2.94/2.98
7.5	2.93/3.14	2.91/3.06	2.88/3.00	2.87/2.97	2.86/2.93	2.84/2.90
8	2.85/3.07	2.82/2.99	2.80/2.93	2.79/2.89	2.77/2.85	2.76/2.82
8.5	2.77/3.01	2.74/2.93	2.72/2.86	2.71/2.82	2.69/2.78	2.68/2.75
9	2.70/2.96	2.67/2.87	2.65/2.80	2.63/2.76	2.62/2.71	2.61/2.68
9.5	2.63/2.90	2.60/2.81	2.58/2.74	2.56/2.70	2.55/2.65	2.54/2.62
10	2.56/2.85	2.54/2.76	2.51/2.68	2.50/2.64	2.48/2.59	2.47/2.56
10.5	2.50/2.81	2.47/2.71	2.45/2.63	2.44/2.59	2.42/2.54	2.41/2.51
11	2.44/2.78	2.42/2.73	2.39/2.56	2.38/2.53	2.36/2.49	2.35/2.45
11.5	2.38/2.72	2.36/2.62	2.33/2.54	2.32/2.49	2.30/2.44	2.29/2.40
12	2.33/2.68	2.30/2.58	2.28/2.48	2.26/2.44	2.25/2.39	2.23/2.36
12.5	2.28/2.64	2.25/2.54	2.23/2.45	2.21/2.40	2.19/2.35	2.18/2.31
13	2.23/2.61	2.20/2.50	2.18/2.41	2.16/2.36	2.14/2.30	2.13/2.27
13.5	2.18/2.57	2.15/2.47	2.13/2.37	2.11/2.32	2.09/2.25	2.08/2.23
14	2.13/2.54	2.11/2.43	2.08/2.34	2.07/2.29	2.05/2.23	2.03/2.19

Erosion Factor - No Dowels, No Concrete Shoulder (Single Axle / Tandem Axle)

Slab thickness, in.	k of subgrade-subbase, pci					
	50	100	200	300	500	700
4	3.94/4.03	3.91/3.95	3.88/3.89	3.86/3.86	3.82/3.83	3.77/3.80
4.5	3.79/3.91	3.76/3.82	3.73/3.75	3.71/3.72	3.68/3.68	3.64/3.65
5	3.66/3.81	3.63/3.72	3.60/3.64	3.58/3.60	3.55/3.55	3.52/3.52
5.5	3.54/3.72	3.51/3.62	3.48/3.53	3.46/3.49	3.43/3.44	3.41/3.40
6	3.44/3.64	3.40/3.53	3.37/3.44	3.35/3.40	3.32/3.34	3.30/3.30
6.5	3.34/3.56	3.30/3.46	3.26/3.36	3.25/3.31	3.22/3.25	3.20/3.21
7	3.26/3.49	3.21/3.39	3.17/3.29	3.15/3.24	3.13/3.17	3.11/3.13
7.5	3.18/3.43	3.13/3.32	3.09/3.22	3.07/3.17	3.04/3.10	3.02/3.06
8	3.11/3.37	3.05/3.26	3.01/3.18	2.99/3.10	2.96/3.03	2.94/2.99
8.5	3.04/3.32	2.98/3.21	2.93/3.10	2.91/3.04	2.88/2.97	2.87/2.93
9	2.98/3.27	2.91/3.16	2.86/3.05	2.84/2.99	2.81/2.92	2.79/2.87
9.5	2.92/3.22	2.85/3.11	2.80/3.00	2.77/2.94	2.75/2.86	2.73/2.81
10	2.86/3.18	2.79/3.08	2.74/2.95	2.71/2.89	2.68/2.81	2.66/2.76
10.5	2.81/3.14	2.74/3.02	2.68/2.91	2.65/2.84	2.62/2.74	2.60/2.70
11	2.77/3.10	2.69/2.98	2.63/2.86	2.60/2.80	2.57/2.72	2.54/2.67
11.5	2.72/3.06	2.64/2.94	2.58/2.82	2.55/2.76	2.51/2.68	2.49/2.63
12	2.68/3.03	2.60/2.90	2.53/2.78	2.50/2.72	2.46/2.64	2.44/2.59
12.5	2.64/2.99	2.55/2.87	2.48/2.75	2.45/2.68	2.41/2.60	2.39/2.55
13	2.60/2.96	2.51/2.83	2.44/2.71	2.40/2.65	2.36/2.56	2.34/2.51
13.5	2.56/2.93	2.47/2.80	2.40/2.68	2.36/2.61	2.32/2.53	2.30/2.48
14	2.53/2.90	2.44/2.77	2.36/2.65	2.32/2.58	2.28/2.50	2.25/2.44

Single axle:

$$\text{Erosion factor} = 2.6 - \frac{0.02}{50} \times 30 = 2.59$$

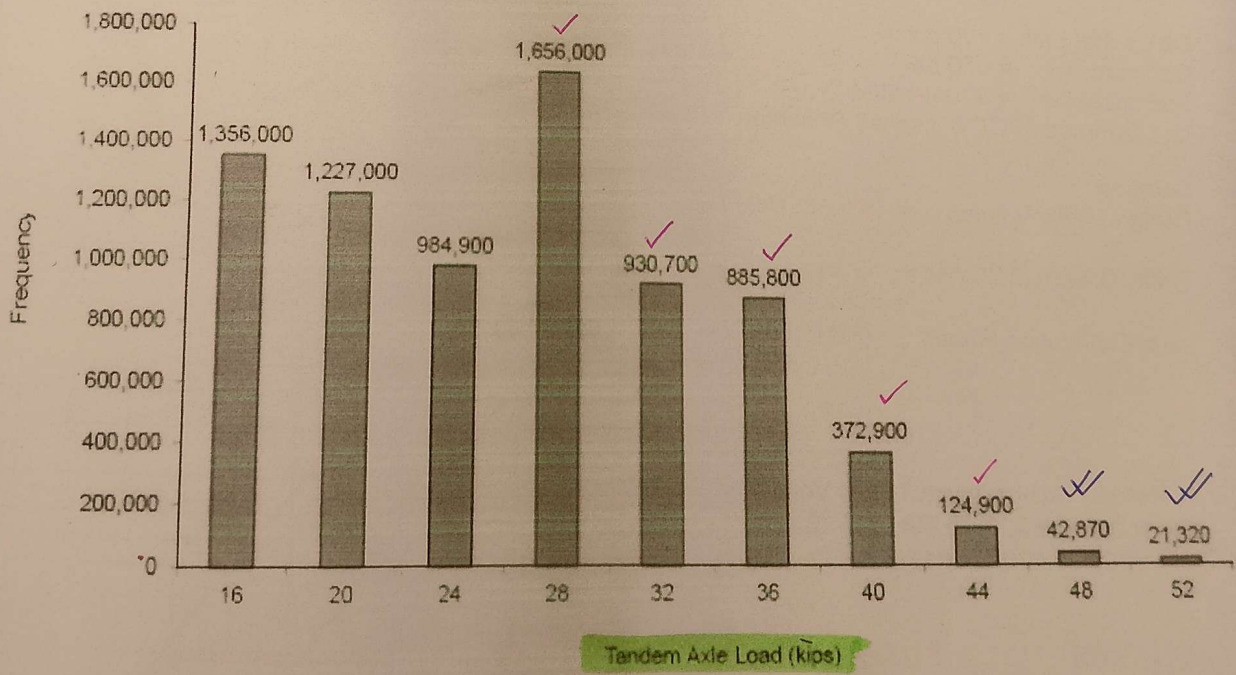
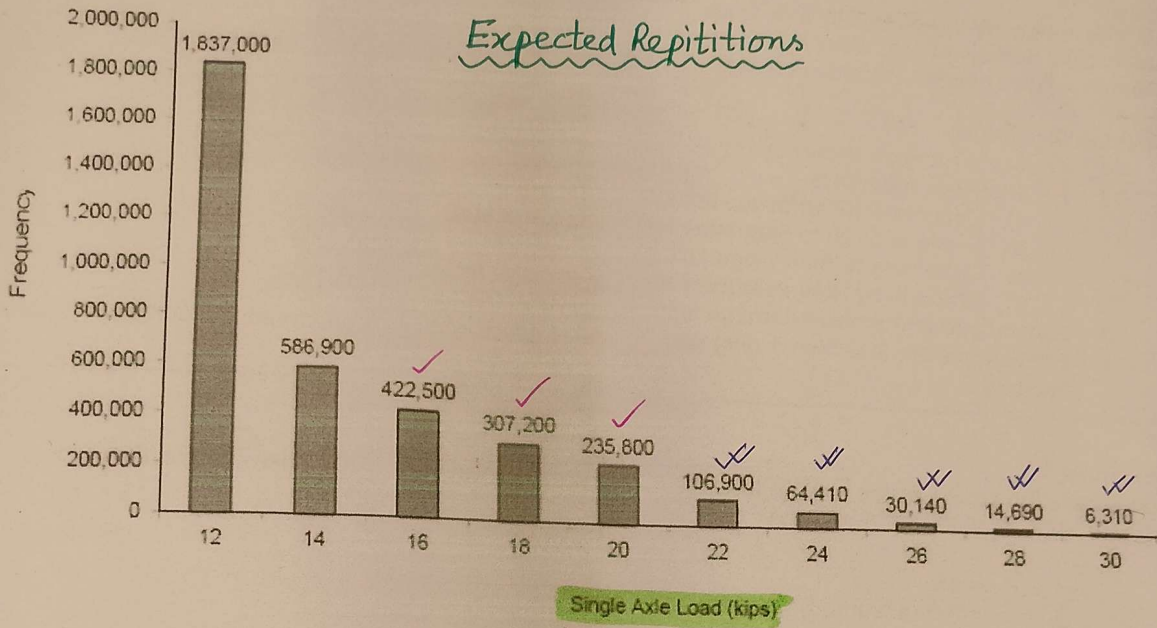
(for slab thickness 9.5 inch  
& subbase - subgrade  $K = 130 \text{ pci}$ )

Tandem axle:

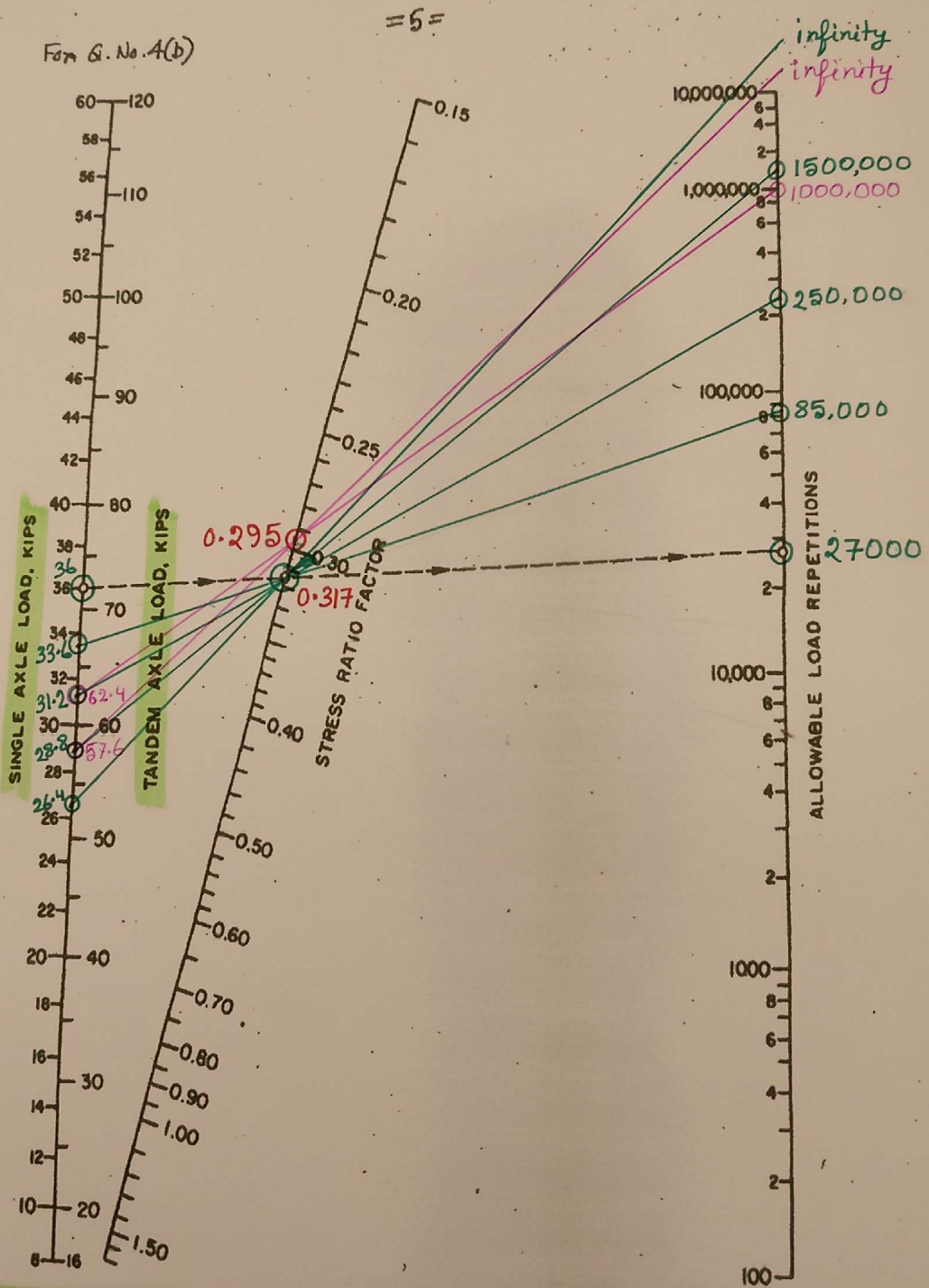
$$\text{Erosion factor} = 2.81 - \frac{0.07}{50} \times 30 = 2.79$$

### Axle Load Spectrum

Expected Repetitions



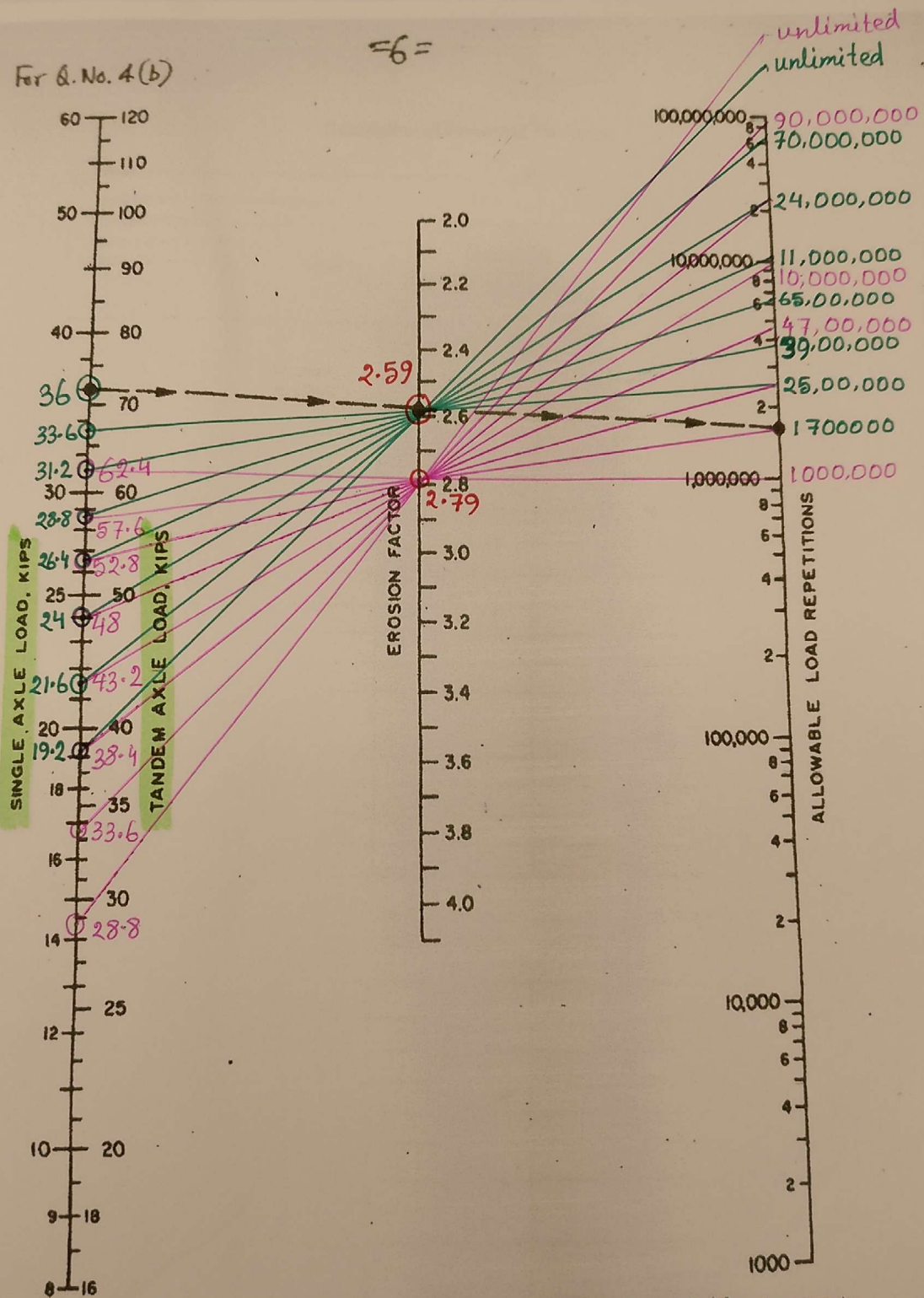
Form 6. No. 4(b)



Fatigue analysis—allowable load repetitions based on stress ratio factor (with and without concrete shoulder).

For Q. No. 4(b)

=6=



Erosion analysis—allowable load repetitions based on erosion factor (without concrete shoulder).

### Calculation of Pavement Thickness

Project \_\_\_\_\_  
 Trial thickness 9.5 in      Doweled joints    yes  no \_\_\_\_\_  
 Subbase-subgrade, k 130 pci      Concrete shoulder    yes \_\_\_\_\_ no   
 Modulus of Rupture, MR 650 psi      Design Period 20 years  
 Load safety factor, LSF 1.2

Axle Load, kips	Multiplied by LSF	Expected repetitions	Fatigue analysis		Erosion Analysis	
			Allowable repetitions	Fatigue Percent	Allowable repetitions	Damage Percent
1	2	3	4	5	6	7

8. Equivalent stress  $\frac{2.06}{0.317}$       10. Erosion factor 2.59

Single Axles

30	36	6310	27000	23.4	1700,000	0.37
28	33.6	14690	85000	17.3	2500,000	0.6
26	31.2	30140	250,000	12.1	3900,000	0.77
24	28.8	64410	1500,000	4.3	6500,000	1.0
22	26.4	106900	unlimited	0	11000,000	0.97
20	24	235800		$\Sigma = 57.1$	24000,000	0.98
18	21.6	307200			70000,000	0.44
16	19.2	422500			unlimited	0
						$\Sigma = 5.13$

11. Equivalent stress  $\frac{192}{0.295}$       13. Erosion factor 2.79

Tandem Axles

52	62.4	21320	1000,000	2.132	1600,000	2.13
48	57.6	42870	unlimited	0	1700,000	2.52
44	52.8	124900		$\Sigma = 2.132$	2500,000	5.0
40	48	372900			4700,000	7.93
36	43.2	885800			10000,000	8.9
32	38.4	930700			24000,000	3.9
28	33.6	1656000			90000,000	1.84
24	28.8	984900			unlimited	0
						$\Sigma = 32.22$

Total = 59.232

Total = 37.35

Comments :

First trial with  $t = 9.5$  inch

$$\text{Total Fatigue \& Damage} = \text{Fatigue\%} + \text{Damage\%}$$

$$= 59.232 + 37.35$$

$$= 96.582\% , \text{ which is acceptable}$$

So, Design thickness =  $t = 9.5$  inch

Notes

i) If total fatigue and damage  $\ll 100\%$

assumed thickness was over estimated

2nd trial needed with reduced thickness

ii) If total fatigue and damage  $\gg 100\%$

assumed thickness was under estimated

2nd trial needed with increased thickness



## Problem-7

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### Example 2

Design the thickness of a concrete pavement using PCA method for the conditions given below:

#### General Data

Traffic (Average Daily Traffic, ADT):	400 veh/day (both directions)
Trucks:	20 percent of ADT
Annual growth:	3 percent
Modulus of Rupture, $M_R$ :	650 psi
Modulus of Subgrade Reaction, $k$ :	100 pci
Design life:	20 years

#### Truck Axle Distributions

Axle Load Group (kips)	No. axles per 100 trucks on the road	
	Single Axles	Tandem Axles
12-14	8.0	
14-16	7.3	
16-18	6.1	
18-20	5.4	
20-22	3.2	
22-24		7.6
24-26		8.4
26-28		9.0
28-30		11.2
30-32		9.4
32-34		1.8
34-36		1.4
36-38		0.9
38-40		1.0
40-42		0.1
42-44		0.1
44-46		0.1

## Reinforcement Details of Rigid Pavement

### 1) Temperature / Distributed Reinforcements

→ usually in both directions in the form of welded wire-mesh or bar-mat

### 2) Dowel Bars

→ applied only in longitudinal direction and across the expansion & contraction joints

→  $\frac{25\text{ mm (\#8)}}{\text{transverse joint}}$  or  $\frac{32\text{ mm (\#10)}}{\text{contraction joint}}$  in size  
600 mm (2') long

spaced  $\frac{\text{@ } 200\text{ mm (8")}}{\text{transverse joint}}$  to  $\frac{300\text{ mm (12")}}{\text{contraction joint}}$  c/c

→ become necessary for longer span i.e. > 12 m or 40 ft

→ placed at mid depth of the slab

### 3) Tie Bars

→ they are not so heavy and are smaller than dowel bars & spaced at greater intervals

→ Usually 12 mm (#4) - 19 mm (#5) bars are used

## Calculation of Reinforcement

$$\textcircled{1} \quad A_s = \frac{Wf}{f_s} \times L$$

$A_s$  = steel per foot of width

$W$  = Weight of slab ( $\text{lb}/\text{ft}^2$ )

$f$  = Co-efficient of resistance  
(generally assumed to be 1.5)

$f_s$  = Allowable stress of steel  
(psi)

$L$  = Length of slab

\*\*  $\left\{ \begin{array}{l} L = L/2 \text{ (longitudinal direction)} \\ L = L \text{ (transverse direction)} \end{array} \right.$   
w.r. to edge restraint condition

$\textcircled{2}$  Length of tie bar,

$$t \text{ (inch)} = \frac{0.5 f_s d_b}{f_b} + 3''$$

$d_b$  = dia of bar (inch)

$f_b$  = Bond strength

(usually 10% of compressive strength of concrete)

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Example

Design reinforcement for the following:

Thickness of rigid part., t =	12 inch
No of lanes =	2
Width of pavement, w =	24 ft
Spacing of transverse joint =	45 ft (Contraction Joint @ 22.5ft)
<b>Allowable strength of:</b>	
Shrinkage steel (bar-mat) =	33000 psi
Tie bars =	27000 psi
Bond =	350 psi (10% of comp. strength of concrete)

Draw reinforcement and joint details.

Amount of shrinkage reinforcement,

$$A_s (\text{in}^2/\text{ft}) = \frac{Wf}{f_s} L$$

Weight of slab,  $W = 150 \text{ pcf} \times \text{thickness}$   
 $(\text{lb}/\text{ft}^2) = 150 \times \frac{12}{12}$   
 $= 150 \text{ lb}/\text{ft}^2$

Co-efficient of resistance,  $f = 1.5$  (assumed)

Allowable strength of steel,

for shrinkage steel,  $f_s = 33000 \text{ psi}$

for Tie bars,  $f_s = 27000 \text{ psi}$

① Distributed temperature reinforcement:

• In longitudinal direction,

$$L = \text{spacing of transverse joint} / 2$$
$$= 45 / 2$$
$$= 22.5 \text{ ft}$$

$$\text{So, } A_s = \frac{150 \times 1.5}{33000} \times 22.5$$

$$A_s = 0.153 \text{ in}^2/\text{ft}$$

Let us use #4 bars,

$$\therefore \text{spacing (ft)} = \frac{\text{Area of bar}}{A_s}$$

$$= \frac{0.20}{0.153}$$

$$= 1.307 \text{ ft}$$

$$\approx 1 \text{ ft c/c}$$

#4 @ 1ft c/c

In transverse direction,

$$\begin{aligned} L &= \text{width of pavement} / 2 \\ &= 24' / 2 \\ &= 12' \end{aligned}$$

$$\text{So, } A_s = \frac{150 \times 1.5}{33000} \times 12 = 0.082 \text{ in}^2/\text{ft}$$

Let us use, #4 bar

$$\therefore \text{spacing} = \frac{0.20}{0.082} = 2.44 \text{ ft} \approx 2 \text{ ft c/c}$$

#4 @ 2 ft c/c

② Tie bars along longitudinal construction joints:

$$\begin{aligned} L &= \text{width of pavement} / 2 \\ &= 24' / 2 \\ &= 12' \end{aligned}$$

$$\text{So, } A_s = \frac{150 \times 1.5}{27000} \times 12 = 0.1 \text{ in}^2/\text{ft}$$

Let us use, #5 bar

$$\therefore \text{spacing} = \frac{0.31}{0.1} = 3.1 \text{ ft} \approx 3 \text{ ft c/c}$$

Length of tie bar,

$$l \text{ (inch)} = \frac{0.5 f_s d_b}{f_b} + 3''$$

$$d_b = \text{dia of tie bar (inch)} = \frac{5}{8} \text{ inch}$$

$$f_s = 27000 \text{ psi}$$

$$f_b = 350 \text{ psi}$$

$$\therefore l \text{ (inch)} = \frac{0.5 \times 27000 \times \frac{5}{8}}{350} + 3''$$

$$= 27.11 \text{ inch}$$

$$\approx 2 \text{ ft}$$

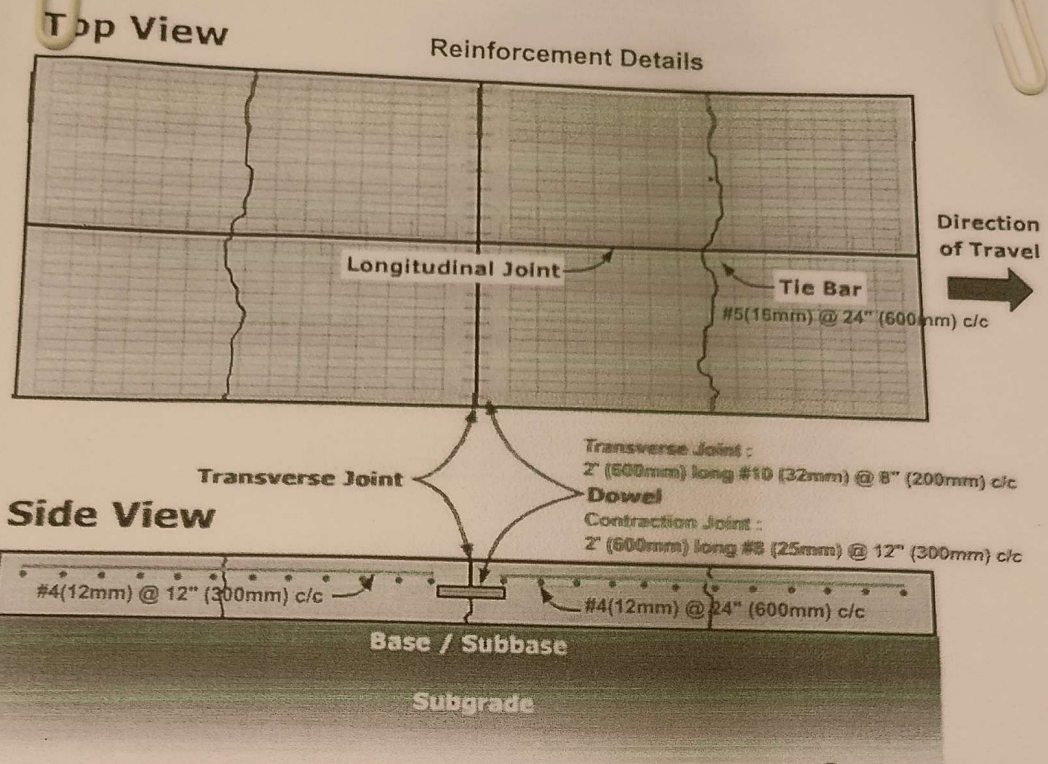
#5 @ 3 ft c/c

2 ft length

③ Dowel bars across Transverse & Contraction joints:

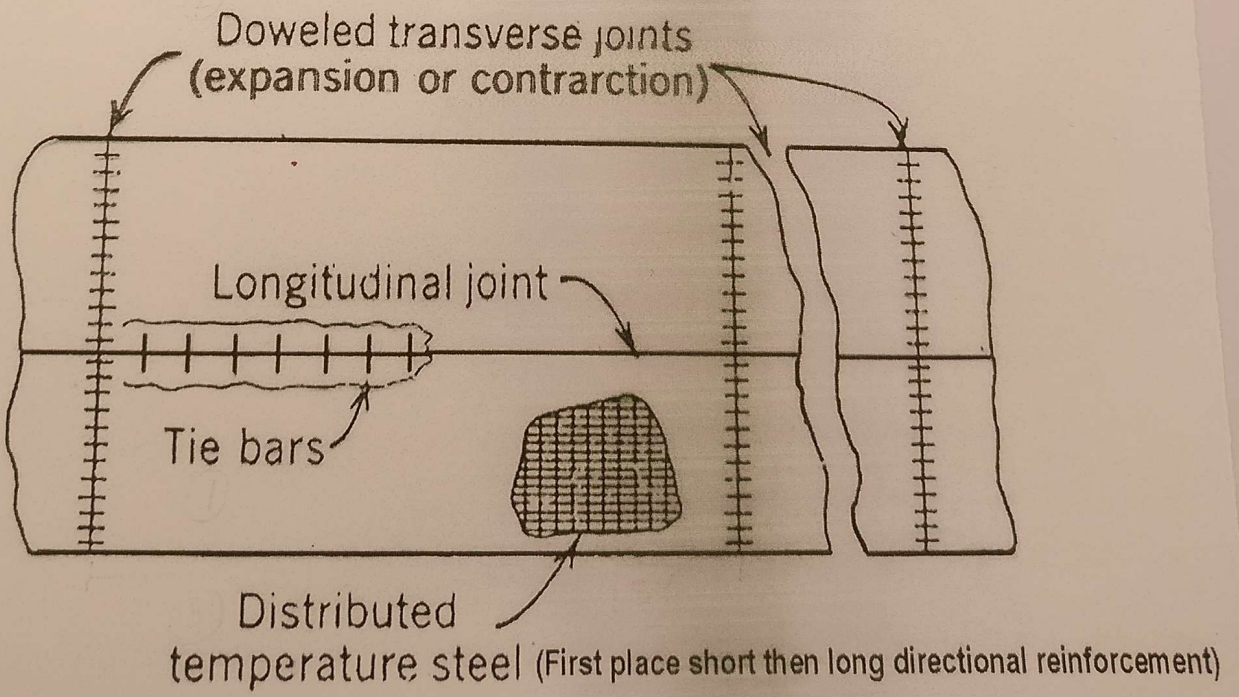
By default:

	Transverse Joint	Contraction joint
Bar size	# 10	# 8
Length	2 ft	2 ft
Spacing	8 in c/c	12 in c/c



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**Jointed Reinforced Concrete Pavement (JRCP)**



# Flexible Pavement Design

## RHD Method

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**Appendix 2: Example of Pavement Design**

Background: An existing 6.2m Regional Road that is located on an embankment requires full reconstruction. A check has been made and the existing road surface is 1.0m above the Highest Flood Level for a 50 year return period. Accordingly the embankment does not require to be raised.

A number of trial pits were undertaken and the CBR of the sub-grade beneath the existing road was found to be 3%.

A 24 hour classified traffic count was carried out on a typical weekday.

Vehicle Categories	Base year Two-way Flow/day
Heavy truck	40
Medium truck	300
Light truck	100
Large bus	200

Vehicle Category	Equivalence Factor
Large Truck (dual axle)	4.8
Medium Truck (Single axle)	4.62
Small Truck	1.0
Large Bus	1.0
Mini Bus	0.5

**Table 3: Vehicle Equivalence Factors**

*(sometimes table-3 not given)*

Half of the two-way flow of commercial vehicles is used to determine the cumulative ESAs over the design life of the road -

Vehicle Categories	Base year two-way flow/day (a)	Existing flow/day $0.5 \times \text{two way flow}$ (b)	ESA factor Table-3 (c)	Existing ESAs/day $(b) \times (c)$	Annual ESAs $(b) \times (c) \times 365$
Heavy Truck	40	20	4.8	96	35040
Medium Truck	300	150	4.62	693	252945
Light Truck	100	50	1.0	50	18250
Large bus	200	100	1.0	100	36500
Total				=	342735

Road Type	Factor
National Road	57.3
Regional Road	41.0

Table 4: Cumulative Growth Factors

(sometimes not given)

From table-4, using the appropriate factor for a regional road,

$$\begin{aligned}
 &\text{Cumulative EASs over the design life for the road} \\
 &= \text{Total annual EASs} \times \text{Cumulative growth factor} \\
 &= 342735 \times 41.0 \\
 &= 14052135 \text{ EASs} \\
 &= 14 \text{ million EASs}
 \end{aligned}$$

For new roads and the full depth reconstruction of existing roads the following design standards are to be adopted:

RHD design always constant

	Pavement Design Life	Traffic Growth Rate
National Road	20 years	10% pa
Regional Road	20 years	7% pa

Table 2: Pavement Design Life and Traffic Growth Rates

Table-2  
[must be memorised]

If table-4 is not given, cumulative growth factor can be determined by using table-2

Regional road: Traffic growth factor =  $\frac{(1+r)^n - 1}{r} = \frac{(1+0.07)^{20} - 1}{0.07} = 41.0$

National road: Traffic growth factor =  $\frac{(1+0.1)^{20} - 1}{0.10} = 57.3$

\*\*\*  
Extra

CBR Required	Compacted Thickness of additional layer to provide required CBR			
	CBR of Underlying layer			
	2%	3%	4%	5%
5%	450 mm	300 mm	250 mm	200 mm

**Table 6: Improved Sub-grade Requirements**

In all cases, sub-grade material with a CBR of less than 2% should be removed and replaced with fill material complying with Section 2.6 of the RHD Specification

As CBR of the subgrade is 3%,  
 according to table - 6,  
 300 mm of improved subgrade will be required to  
 achieve a subgrade strength of 5% CBR.

*Determination of Pavement Layers*

The estimated cumulative ESAs are then used to determine the various pavement layers from the following design chart:

mm	Surfacing (mm)		Roadbases (mm)* (Select one type)		Sub-bases (mm)** Subgrade CBR %				
	Traffic ESA (mill)	Asphalt Wearing Course	Asphalt Base- Course	Cement- bound Granular	Granular Base Type I	Type II	8 - 25	> 25	
60 - 80		40	155		N/A	N/A	300	150	0
40 - 60			140		250	300	250		
30 - 40			125				250		
25 - 30			110				200		
17 - 25			105				200		
15 - 17		40	95		250	250	200		
11 - 15	14 million		90		200	250	200		
9 - 11			80						
7 - 9			70						
6 - 7			65						
5 - 6			60						
4 - 5			55						
3 - 4			45		175	200	175		
< 3			35		150	175	150		

Refer to BRRL for design advice

\* CBR of granular base type I is min. 80%      N/A. = not applicable  
 \* CBR of granular base type II is min. 50%  
 \*\* CBR of sub-base material is 25%

**Table 5: Thickness Design Table for Flexible Pavements**

Now, According to the  
design chart in table-5.

the required pavement layers will be :

DBS : 130 mm (40 mm Asphalt wearing course +  
90 mm Asphalt base course)

Base type 1 : 250 mm

Subbase : 200 mm

Improved subgrade : 300 mm

---

## Flexible Pavement Design

### Catalogue of Pavement Structures Method

Design of flexible pavement for an undivided rural highway by using Catalogue of Pavement Structures method includes —

#### ① Determination of roadway geometry

- $\text{PCU/day} = \text{Traffic volume} \times \text{PCU factors}$   
(in base year)
- Forecasted design flow (in design year)

$$= \text{PCU/day in base year} \times (1+r)^n$$

$r$  = growth rate

$n$  = design period

Then using maximum design capacity from

Manual of Geometric Design standards,

Roadway geometry is determined

## ② Determination of Cumulative ESAL for Pavement design

Considering damaging effect,

only heavy vehicles are taken into account.

Heavy vehicles  $\rightarrow$   $\left\{ \begin{array}{l} \text{Large truck} \\ \text{Small truck} \\ \text{Large Bus} \\ \text{Small Bus} \end{array} \right.$

$$\text{Cumulative ESAL (per vehicle)} = 365 \times \text{AADT} \times \text{ESAL} \times \frac{(1+r)^n - 1}{r}$$

ESAL per vehicle  $\rightarrow$  Table 2

$r$   $\rightarrow$  growth rate

$n$   $\rightarrow$  design period

Total Cumulative ESAL in both direction

$$= \Sigma \text{ Cumulative ESAL}$$

Total Cumulative ESAL in one direction

$$= \text{Directional distribution} \times \text{Total cumulative ESAL in both dir}^n$$

$$= 0.50 \times \text{Total cumulative ESAL in both dir}^n$$

\* Determination of the Channelisation factor -

Proportion of non-motorised traffic, to heavy vehicle,

Bicycle  
Rickshaw  
Cart

Large truck  
Small truck  
Large bus  
Small bus

$$P = \frac{\Sigma \text{AADT of non motorised traffic}}{\Sigma \text{AADT of heavy vehicle}}$$

Using road width and P,

from table 3, Channelisation factor is determined.

$$\text{True design Cumulative traffic} = \text{Total cumulative ESAL in one dir}^n \times \text{Channelisation factor}$$

$$= \text{ESA}$$

$$= \text{MSA}$$

### ③ Determination of Pavement layer thickness

Using true design cumulative traffic (in MSA)

from table 4 → Traffic class is determined

Using CBR

from table 5 → Subgrade class is determined

Problem-10

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Design flexible pavement for an undivided rural highway by using Catalogue of Pavement Structures Method for the following data.

Given:

The forecast AADT for 2033 the year of opening, is assessed as:

Vehicles Types	Two-way AADT vpd
Large Truck	104
Small Truck	115
Large Bus	500
Small Bus	50
Car	300
Autorickshaw	100
Motor Cycle	150
Bicycle	100
Rickshaw	500
Cart	10

Assume:

Growth rate, $r =$	8 % per annum
Design period, $n =$	15 year
CBR of Subgrade =	12 %

Solution

A) Determination of Roadway Geometry —

Table 1: PCU Factors for Rural Road

Vehicle Types	PCU Factors
Large Truck	3.0
Small Truck	2.0
Large Bus	2.5
Small Bus	1.5
Car/Tempo	1.0
Autorickshaw	0.5
Motor Cycle	0.3
Bicycle	0.3
Rickshaw	2.0
Cart	4.0

Vehicle Types	Traffic Volume at 2003	PCU factors	PCU/day at 2003
	AADT	Table 1	Traffic vol <sup>m</sup> x PCU factors
Large Truck	104	3.0	312
Small Truck	115	2.0	230
Large Bus	500	2.5	1250
Small Bus	50	1.5	75
Car	300	1.0	300
Auto rickshaw	100	0.5	50
Motorcycle	150	0.3	45
Bicycle	100	0.3	30
Rickshaw	500	2.0	1000
Cart	10	4.0	40
Total =			3332

Forecasted design flow in 2018 (after 15 years)

$$= 3332 \times (1+r)^n$$

$$= 3332 \times (1+0.08)^{15}$$

$$= 10570 \text{ PCU/day}$$

### National Roads-Cross-Section Design Capacities

Cross-Section	Optimum Design Capacity (PCU/Hour)	Maximum Capacity (Daily)	Design Year Optimum Demand Flow Range (PCU/Hours) (3)	Application	
				New Construction	Widening w.r.t. RHD (2)
RHD 6.7m	1000 (Daily = 14,000) (Note 3)		1 to 1000	Not applicable. New 7.4m standard always has a better overall economic performance.	No widening necessary if demand flows less than 1000 PCU/hours
4.7m + Pre-widening of embankment to 11m standard	1900 (Daily = 27,000)		1 to 1900 (New Construction) 1001 to 1900 (Widening)	The standard new minimum width for National road with the high mobility function	If traffic demand is above 1000 PCU/Hours widening justified and can be easily carried out by re-arranging the road layout on the existing embankment crest width.
11m + Pre-widening of embankment to 4 x 3.7m standard	(2200)		(1900 - 2200) But, optimal flow range too narrow to be usefull.	Not applicable as a final design standard but usefull as part of stage construction on way to the high level 4 x 3.7m section.	Not applicable due to narrow optimal flow range and due to practical difficulties of widening from 6.7m to 11.0m under trafficking.
4 x 3.7m + Pre-widening of embankment to 6 x 3.67m standard.	4500 (Daily = 64,000)		1901 to 4500	A very useful width for high volume roads at a future date.	An economical widening choice for the basier National roads in Bangladesh.
6 x 3.67m	7500 (Daily = 105,000)		4501 to 7500	New roads needing this capacity very unlikely to develop.	Will undoubtedly have its application on the busiest roads, or in future second round widening.

- Notes :
- 1) Real flow Peak Hour Factor of 0.07 taken.
  - 2) It is assumed that all widening takes place from a 6.7m RHD base.
  - 3) This design year flow range was demonstrated by the analysis to be optimal even if traffic growth on a particular project is forecast to be other than 8%, & anywhere between 5.6% & 9.2% (the sensitivity analysis is outer margings).

### Regional Roads-Cross-Section Design Capacities

Cross-Section	Optimum Maximum Design Capacity (PCU/Hour)	Design year Optimum Demand Flow (PCU/Hour)	Application	
			New Construction	Widening w.r.t RHD
RHD 5.5 m	750 (Daily 8300) (Note 1)	1 to 750	Not applicable New 6.2m standard already has a better overall economic performance	No widen necessary of demand flows less than 750 PCU/Hour
6.2 m + Pre-widening of embankment to 7.4m standard Shoulder 7.4-6.2=1.2m	1700 (Daily = 18,500) <i>PCU/hour</i> ↑ <i>max<sup>m</sup></i> <i>PCU/day</i>	1 to 1700 (New Const.) 751 to 1700 (Widening)	The standard new minimum width for Regional roads	If traffic demand above 750 PCU/Hour widening can be easily carried out by re-arranging the road layout on the existing embankment width
7.4m + pre-widening of embankment to 11m stand ard.	(1900)	(1700-1900) But, optimal flow range too narrow to be usefull	Not applicable as a find design standard but usefull part of stage construction on way to the top cross-section of 11 m.	Not applicable due to various optimal flow range and due to practical difficulties of widening 5.5m to 7km under traffic.
11m	2500 (Daily = 28,000)	1701-2500	Not likely that many completely new roads would need to adopt this standard at the out set.	An economical widening choice for the bu: ier Regional roads in Bangladesh.

From the manual of Geometric Design standards,

Road Class = Regional Category

Road width = 6.2 m

Shoulder width = 1.2 m (total)

B) Determination of Cumulative ESAL for Pavement design

Table 2: ESAL per Vehicle

Vehicle Types	ESAL Per veh
Large Truck (10-Wheeler)	4.80
Medium Truck (6-Wheeler)	4.62
Small Truck (4-Wheeler)	1.00
Large Bus	1.00
Small Bus	0.50

Considering damaging effect, only heavy vehicles are taken into account

Heavy Vehicles Types	Two-way AADT	EASL per vehicle	Cumulative ESAL
	vpd	Table 2	$365 \times \text{AADT} \times \text{EASL} \times \frac{(1+r)^n - 1}{r}$
Large Truck	104	4.80	4947332
Small Truck	115	1.0	1139710
Large Bus	500	1.0	4955261
Small Bus	50	0.5	247763
Total =			11290066

Total Cumulative ESAL in both direction = 11290066

Total Cumulative ESAL in one direction

$$= \text{Directional distribution} \times 11290066$$

$$= 0.5 \times 11290066$$

$$= 5645033$$

### Determination of the Channelisation factor

The proportion of non-motorised traffic to heavy vehicle

$$P = \frac{100 + 500 + 10}{104 + 115 + 500 + 50} = 0.79$$

Table 3: Channelisation Factor

Road Width		Channelisation Factor depending on the ratio of NMV to be applied to 1-way flow	
m	ft	Low (<0.5)	High (>=0.5) $\approx 0.79$
5.6 $\downarrow$ 6.2m	18.4	2.0	$\downarrow$ 2.0
6.8	22.3	1.0	$\downarrow$ 1.8
7.3	23.9	1.0	1.6

For road width 6.2 m and  $P = 0.79$ ,

from table - 3 by interpolation,

$$\text{Channelisation factor} = 2.0 - \frac{0.2}{1.2} \times 0.6$$

$$= 1.9$$

Design cumulative traffic

$$= \text{Total cumulative traffic in one direction} \\ \times \text{Channelisation factor}$$

$$= 5645033 \times 1.9$$

$$= 10725563 \text{ ESA}$$

$$= 10.7 \times 10^6 \text{ ESA}$$

$$= 10.7 \text{ MSA}$$

### c) Determination of Pavement Layer Thickness

Table 4: Traffic Definition

Class	MSA
T0	<0.5
T1	0.5 - 1.5
T2	1.5 - 3.0
T3	3.0 - 7.5
T4	7.5 - 20.0
T5	20 - 30

For 10.7 MSA,

from table-4,

Traffic Class = T4

Table 5: Subgrade Definition

Class	CBR
S1	3 - 5
S2	5 - 7
S3	7 - 10
S4	10 - 15
S5	>15

For CBR = 12%,

from table-5,

Subgrade Class = S4