UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: January 2020

Module Number: CE5302 **Module Name: Highway Engineering Design (N/C)**

[Three Hours]

[Answer all questions. Each question carries TWELVE marks]
All Standard Notations denote their regular meanings

Q1. Existing road between the two towns is to be promoted a high-speed mobility highway while a new highway is designed between two towns as a scenic route with a speed limit of 50 km/h. The new link is proposed to be design as an undivided two lane road. Assuming that you are appointed as the leader of the design team answer the following questions.

a) List 5 sources of data which can be used in the initial design process and explain how could you verify the validity of the data.

[2.0 Marks]

b) Briefly explain processes involved in the traditional four steps of the highway location process.

[5.0 Marks]

c) Compare and contrast a high-speed highway and scenic route design consideration along 3 factors.

[3.0 Marks]

d) Name four factors that should be considered when designing a route through urban area.

[2.0 Marks]

Q2. AASHTO guidelines recommend to use a constant rate of change in the gradient (K given in units of %/m)" for the vertical curve design.

a) If a constant, "K (%/m)", rate of change in the gradient is to be achieved, prove that that vertical curve needs to be a parabola.

[2.0 Marks]

b) At a certain location along the proposed new highway, there are two successive gradients of -4% and -3%. What is the type of vertical curve that should be placed here when referring to Table Q2-1.

[1.00 Mark]

c) Stating assumptions, if any, clearly and referring to the Table Q2-1 determine the length of the vertical curve needed.

[2.0 Marks]

d) If a curve length of 300 m was selected for the curve proposed in in Q2. (c), the elevation of the starting point (T1) of the vertical curve is 345.000 m AMSL and the chain-age is 19+880 m, calculate the following (Refer Figure Q2-1):

i. Elevation of point PI, and midpoint of the curve
ii. Maximum elevation achieved by the curve
iii. Chain-age of Point T2
iv. Copy the Table Q2-2 and fill it considering 50m proper stations.

[7.0 Marks]

Q3. a) With aid of neat sketches compare and contrast the Hammer mills and Jaw crushers with respect to their crushing actions utilised.

[3.00 Mark]

b) In a bench blast activity with a 12m bench height and a hole inclination of 1:10 (1 horizontal: 10 vertical) have been planned for the operation. The economically available explosive is ANFO of density 1250 kg/m^3. The site is characterised by a ground factor of 45. If the company owns a drill machine capable of drilling a hole with a diameter of 100 mm and the drill operator has a starting error of 3 cm and a hole deviation of 2%, determine the following:

i. Sloped length of the drill hole including the under drilling

[3.0 Marks]

ii. Practical overburden (V) and practical hole spacing (E)

[3.0 Marks]

iii. Lengths of stemming (h_o), bottom charge (h_b) and column charge (h_p).

[3.0 Marks]

Q4. Most parts of the proposed highway (stated in Q1) goes through virgin ground. These parts are going to be designed as a granular road base with surface dressing based on Road Note 29 method having 2 lanes in each direction. At a certain stretch CBR value of the existing soil was found to be 14%. Estimated AADT and growth factor of the proposed highway (stated in Q1) by axle load for this stretch is given in Table Q4-1 with their growth factors. Other relevant data are given in Table Q4-2, Table Q4-3, Table Q4-4, Figure Q4-1, and Figure Q4-2. Assume that AADT is having 50/50 directional split.

a) Calculate the equivalent factor for each axle load class given in Table Q4-1 roudup your answers to two decimal places.

[2.0 Marks]

b) Calculate the raw cumulative ESAL ($\widehat{W}_{18}$) if the road is to be designed for 25 years.

[3.0 Marks]

c) Determine the cumulative ESAL (W_{18}) considering the directional factor f_D, lane distribution factor f_L given in Table Q4-2, and Table Q4-3, thereby the strength class and traffic class.

[2.0 Marks]

d) Draw the design cross section for the above highway section.

[2.0 Marks]

e) Explain briefly why for some sections capping layer allowed while disallowed for some sections in RN 29.

[3.0 Marks]

Q5. Urban sections of the proposed highway (stated in Q1) are to be a 6 lane (3 lanes in one direction) dual carriage way road with flexible pavement with three layers. The consultant of this project recommended that these sections should be designed using AASHTO method.

The ground condition in such a stretch is described in Table Q5-1, The road section is predicted to have 60/40 directional distribution. The data to design the pavement is as follows. Data for the three layers are as follows.

Layer 1
Reliability $R = 99\%$; Overall standard deviation $S_O = 0.35$; Estimated total 18- kip equivalent single axis load for entire road $\widehat{W}_{18} = 0.85\ (\times 10^6$ ESAL); Design present serviceability index loss $\Delta\ PSI = 1.0$; and Layer coefficient $a_2 = 0.5$

Layer 2
Layer coefficient $a_2 = 0.5$; Drainage modifying factor $m_2 = 0.9$; and SN $= 3.5$.

Layer 3
Layer coefficient $a_3 = 0.08$, Drainage modifying factor $m_2 = 0.85$ and SN $= 7.5$

a) Calculate the effective roadbed soil resilient modulus for the year using Table Q5-1. You may use the scale given in Figure Q5-1 or use the appropriate equation.
[4.0 Marks]

b) Determine the cumulative EASL (W_{18}) considering the directional factor f_D, lane distribution factor f_L given in Table Q4-2, and Table Q4-3 and hence the structural number needed for layer 1. Use the nomograph given in Figure Q5-2 and **attach the nomograph to your answer sheet.**
[2.0 Marks]

c) Calculate the depths of layer 1, 2 and 3.
[6.0 Marks]

Equations, Figures and Tables

Table Q2-1 Design $k(= {}^{1}/_{K})$ values for Vertical Alignment

	Design speed (km/hr)					
	120	100	85	70	60	50
Desirable minimum K value - Crest curves (not recommended for single carriageways)	182	100	55	30	17	10
Absolute minimum K value - Crest curves	100	55	30	17	10	6.5
Absolute minimum K value - Sag curves	37	26	20	20	13	9
Full overtaking sight distance (FOSD) K value - Crest curve	–	400	285	200	142	100

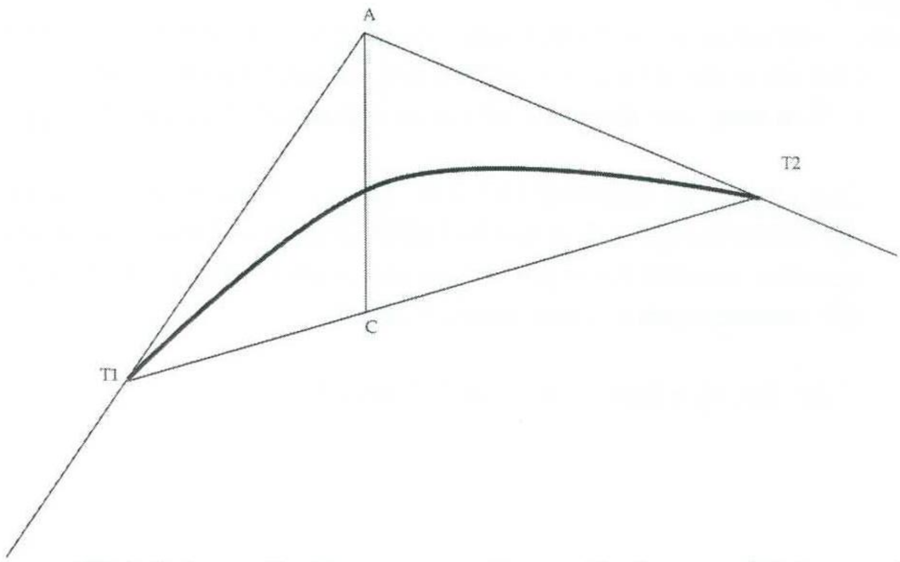


Figure Q2-1 Schematic diagramme of a vertical curve (Not to scale)

Table Q2-2 Setting out table for Vertical curve starting from 20+316

Point	**Chainage**	**Horizontal Length (m)**	**Elevation (m)**
T1	20+316		525.000
P1	20+350		
P_{Max}			
T2			

Table Q3-1 Results of sieve analysis test on combined aggregates (coarse + chips + filler)

Sieve Sizes (mm) 100% passing	Weight Retained (g)
50	0
37.5	100
28	98.5
20	489.3
14	358.2
10	411.5
5	569.5
2.36	156.6
1.18	123.2
300 µm	20.1
75 µm	7.0

Table Q3-2 Extract from Standard specification for construction and maintenance of bridges and roads

Sieve Sizes (mm) 100% passing	Dense Graded Mix Classification 1 Total Weight Passing (%)
50	100
37.5	95 - 100
28	80 - 95
20	-
14	62 - 77
10	-
5	-
2.36	30 - 45
1.18	-
300 µm	-
75 µm	3 - 8

Table Q4-1 Estimated AADT and Growth Factor for the Propossed Highway

Axle load (1000 kg)	AADT	GF %	EF	ESAL	Yearly ESAL	for 20 years
3.0	400	6				
4.0	450	7				
5.0	640	7				
6.0	350	5				
7.0	210	5				
8.0	190	3				
9.0	100	2				

Table Q4-2 Directional factor with Directional Distribution

Directional Distribution	Directional factor f_D
50/50	1.00
60/40	0.94
70/30	0.89
80/20	0.83

Table Q4-3: Recommended values for Lane Distribution Factor

Number of Lanes in each direction	Lane Distribution Factor f_L
1	1.00
2	0.80-1.00
3	0.60-0.80
4	0.50-0.75

*use the minimum value of the corresponding factor

Table Q4-4 Traffic and Sub-grade strength classes

(a) Traffic Classes

Traffic Class	10^6 esa Range
T_1	<0.3
T_2	0.3-0.7
T_3	0.7-1.5
T_4	1.5-3.0
T_5	3.0-6.0
T_6	6.0-10.0
T_7	10.0-17.0
T_8	17.0-30.0

(b) Sub-grade Strength Classes

Sub-grade strength class	Range of CBR%
S1	2
S2	3-4
S3	5-7
S4	8-14
S5	15-29
S6	>30

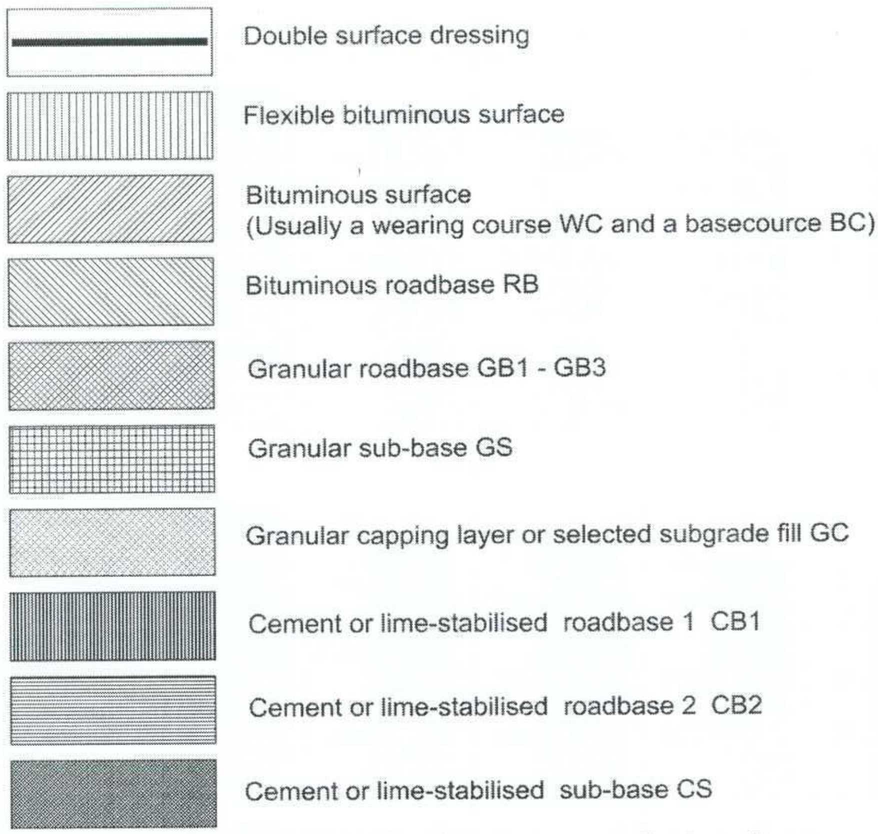
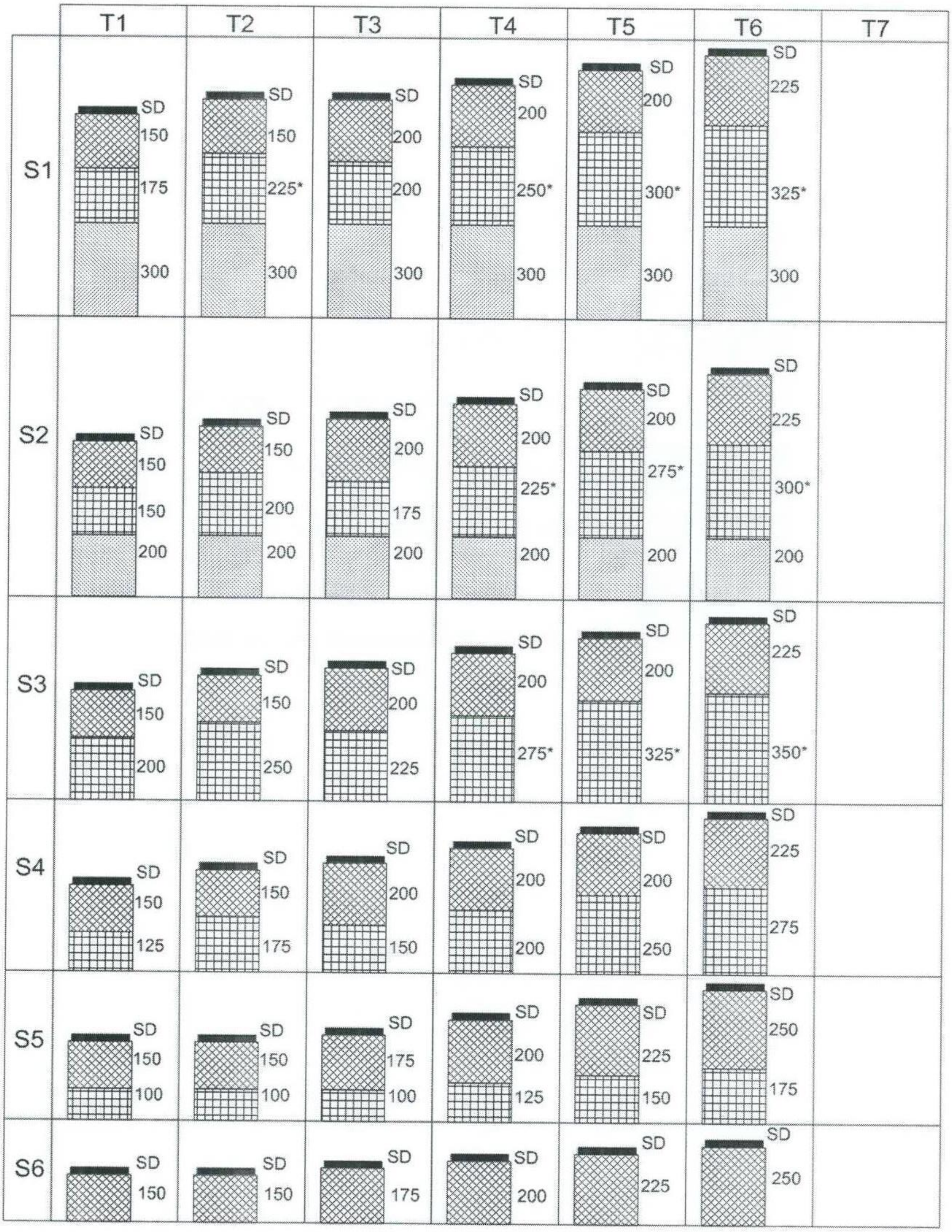


Figure Q4-1 Key for the pavement design charts



Notes		
	1	* Up to 100mm of sub-base may be substituted with selected fill provided the sub-base is not reduced to less than the road base thickness or 200mm whichever is the greater. The substitution ratio of sub-base to selected fill is 25:32.
	2	A cement or lime stabilized sub-base may also be used.
	3	All numbers indicated are in mm unless stated otherwise

Figure Q4-2 Pavement design catalogue for a road granular road base with surface dressing.

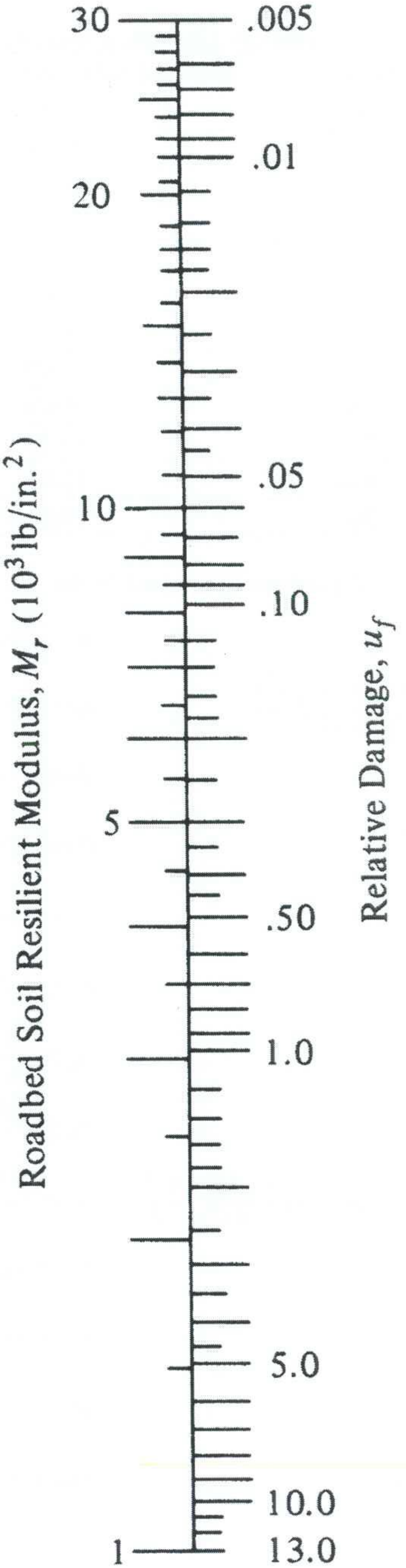


Figure Q5-1 Roadbed resilient modulus and relative damage

Table Q5-1 Roadbed Soil Modulus

Month	Roadbed Soil Modulus MR (psi)
Jan	25,000
Feb	20,000
Mar	18,000
Apr	9,500
May	8,000
June	5,000
July	5,000
Aug	5,000
Sep	9,500
Oct	10,000
Nov	15,000
Dec	20,000

Equations to be used in the calculations

$h_p = H-(h_o+h_b)$

$L = 2d_s - \frac{200 \times (\sqrt{h_1}+\sqrt{h_2})^2}{|G_2 - G_1|}$

$K = \frac{|G_2 - G_1|}{L}$

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

$V_{Max} = C \times d$

$U = 0.3 \times V_{Max}$

$H = (K+u) \times 1.03$

$F = 0.05+0.03 \times H$

$Equvalent\ Factor(EF) = \left(\frac{Axle\ Load}{8160}\right)^{4.5}$

$V = V_{Max} - F$

$E = 1.25 \times V$

$L = |G_2 - G_1| \times k$

$U_f = 1.18 \times 10^8 \times M_r^{-2.32}$

$q_{bk} = 3.14/4 \times d^2 \times P$

$q_{pk} = 0.5 \times q_{bk}$

$Q_b = q_{bk} \times h_b$

$Q_p = q_{pk} \times h_p$

$Q_{tot} = Q_b + Q_p$

$q = Q_{tot} / (K \times V \times E)$

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

$D_2 \geq \frac{(SN_2 - SN_1^*)}{a_2 m_2}$

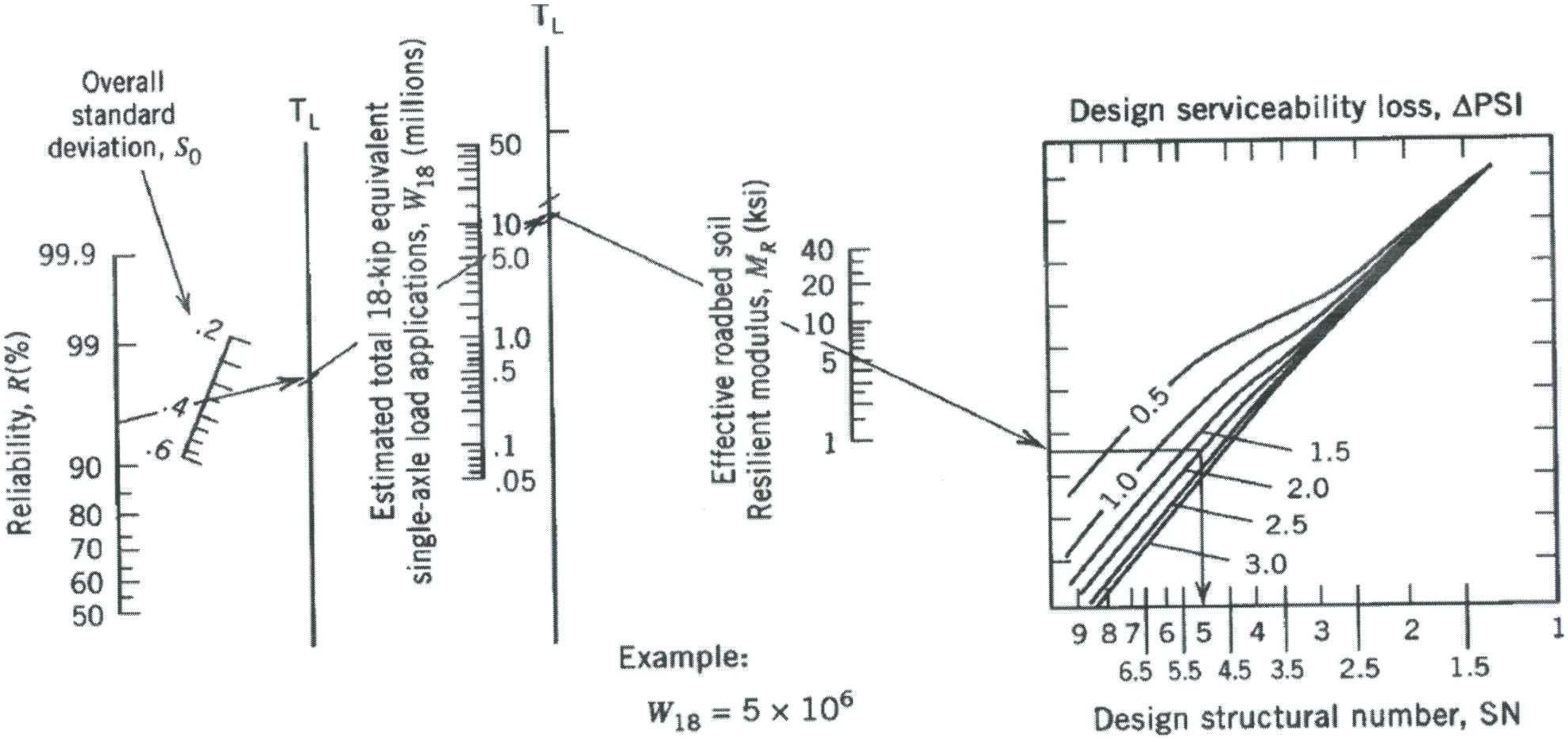
$D_3 \geq \frac{(SN_3 - SN_2^* - SN_1^*)}{a_3 m_3}$

$h_o = V_{Max}$

$h_b = 1.3 \times V_{Max}$

$W_{18} = f_D \times f_L \times \widehat{W}_{18}$

$D_n \geq (SN_n - SN_{n-1}^* \cdots - SN_1^*)/a_n m_n$



Example:

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

$R = 95\%$

$S_0 = 0.35$

$M_R = 5000$ psi

$\Delta PSI = 1.9$

Solution: SN = 5.0