CE361 Introduction to Transportation Engineering — Out: Monday 1 November 2004
Homework 8 **Solutions** — Due: Monday 8 November 2004

PAVEMENT DESIGN

1. **ESAL calculations.** 988 containers per week on 3-S2 trucks. Empty containers weigh 4000 lbs. 55 percent of the containers are loaded to 50,000 lbs. Switch to 3-S2-4?

Truck type	Unloaded weight	Max. Gross Weight	Steering axle load	Max. number of containers	
3-S2	30,000 lbs	80,000 lbs.	12,000 lbs.	1	
3-S2-4	47,000 lbs.	148,000 lbs.	12,000 lbs.	2	

A truck's load is distributed equally over all non-steering axles.
3-S2 is 12K-11K-11K unloaded and 12K-34K-34K loaded.
3-S2-4 is 12K-10.75K-10.75K-10.75K-10.75K unloaded and 12K-33.75K-33.75K -33.75K-33.75K loaded.

A. (10 points) If all containers are now carried by 3-S2's, how many ESALs per week are applied to the concrete access road to the port?

i	kips/axle	Axle Type	Design lane freq/week N(i)	ESAL/axle	ESAL/week
1	12	S	988	0.198	195.160
2	11	T	889	0.021	18.407
3	34	T	1087	1.889	2053.399
					2266.966

B. (10 points) If all containers were instead carried by 3-S2-4's, how many ESALs per week would be applied to the concrete access road?

i	kips/axle	Axle Type	Design lane freq/week N(i)	ESAL/axle	ESAL/week
1	12	S	494	0.198	97.580
2	10.75	T	889.2	0.019	16.790
3	33.75	T	1086.8	1.834	1993.668
					2108.037

Sample calc for 3-S2-4 i=2: kips/axle = ((47-(2*4))-12)/4 = 10.75
For freq/wk: (988 ctrs/2 ctrs per truck) * 4 Tandem axles * 0.45 empty = 889.2

For ESAL/axle by (9.3): $\left(\frac{10.75}{29}\right)^4$ = 0.0189.

2. **Flexible pavement design.** Lifetime ESALs = 6.1 million, R = 95 percent, S.D. = 0.35, ΔPSI = 1.9, M_R values of 18,580 psi (base), 14,590 psi (subbase), and 2300 psi (subgrade).

A. (15 points) Using the design chart, SN_3 = 6.5, SN_2 = 3.5 and SN_1 = 3.2, or values close to these.

B. (15 points) a_1 =0.43, a_2=0.13, a_3=0.09 in (9.6). $SN_1 = a_1 * d_1$; 3.2 = 0.43 d_1; d_1 = 7.44 " → 7.5".
$SN_2 = a_1d_1 + a_2d_2$; 3.5 = (0.43*7.5) + (0.13 * d_2); d_2 = (3.5-3.225)/0.13 = 2.11" → 2.5" → 6.0" by Table 9.7. $SN_3 = a_1d_1 + a_2d_2 + a_3d_3$; 6.5 = (0.43*7.5) + (0.13 * 6.0) + (0.09 * d_3);
d_3 = (6.5 - 3.225 – 0.78)/0.09 = 27.72" → 28.0"

C. (10 points) Cost per lane-mile-inch for each layer in Part B.

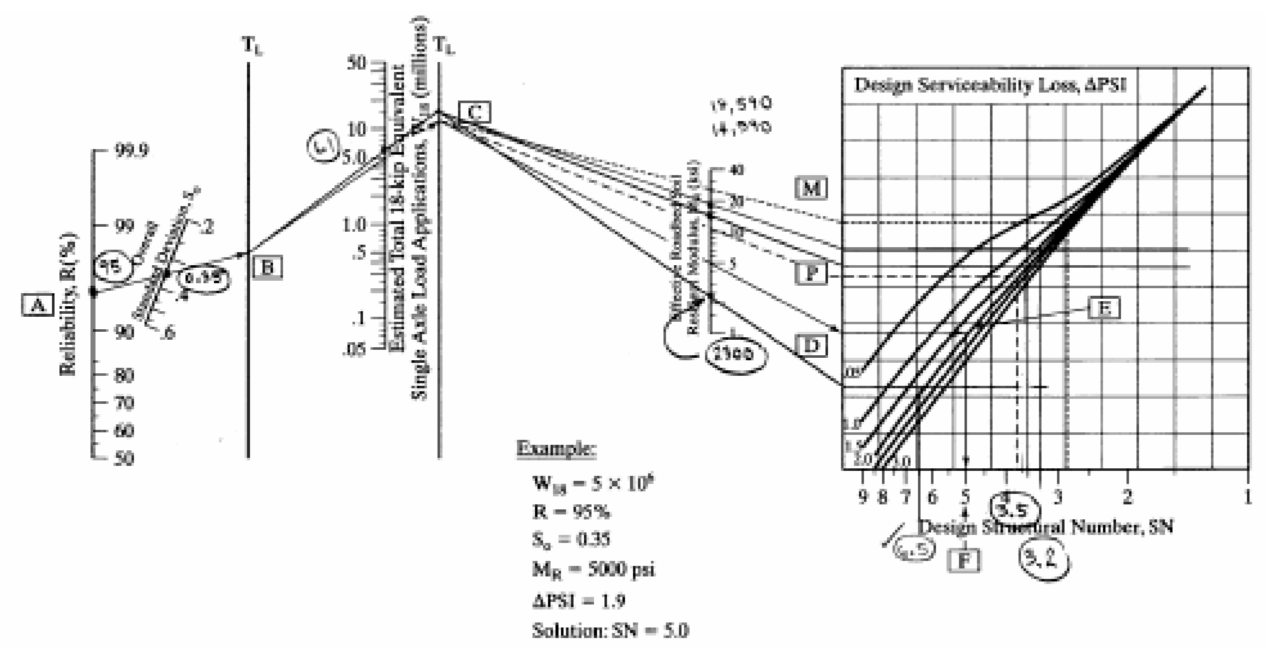
Material	S.G.	lbs/cu ft	tons/la-mi/in.	$/ton	$/la-mi/in.
Hot A.C.	2.65	165.36	436.55	90.00	39289.54
Emulsion/aggregate-bituminous	2.70	168.48	444.79	13.00	5782.23
Coarse Aggreg.	2.30	143.52	378.89	7.00	2652.25
Excavation			$/cu yd:	3	586.67

Total pavement cost for one lane-mile, with excavation and earthwork costs at $3/CY.

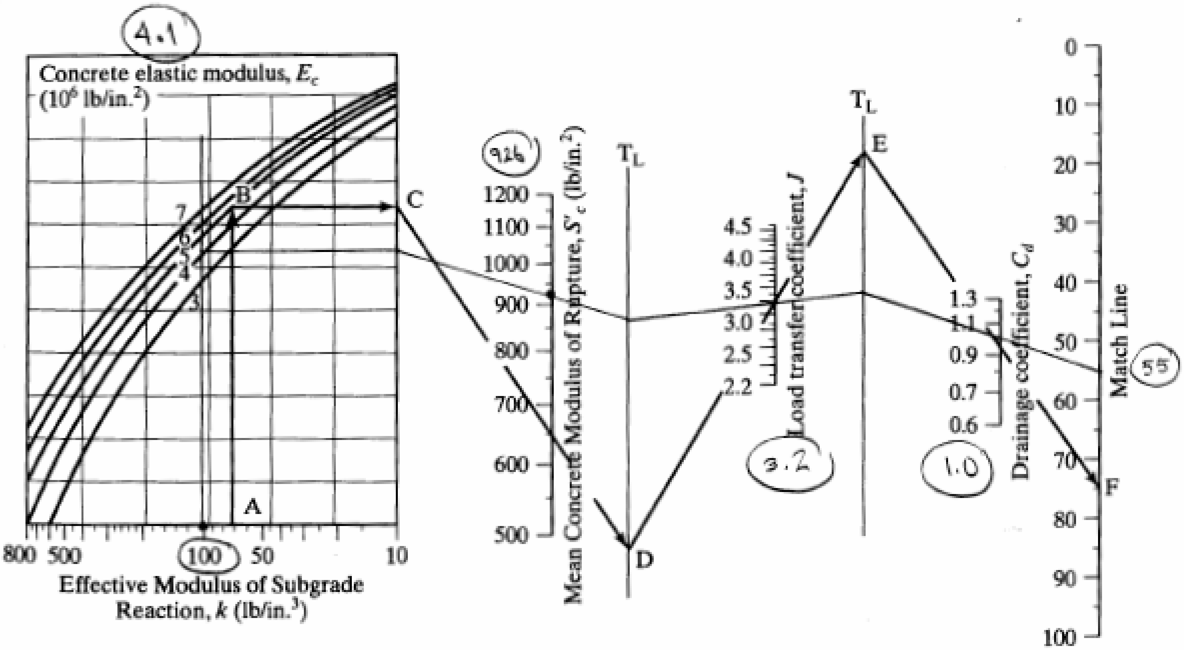
Layer	D(i) to use	$/la-mi
Surface 2"-4"	7.50	$294,672
Base 4"-10"	6.00	$ 34,693
Subbase 4"-10"	28.00	$ 74,263
Excavation	41.50	$ 24,347
	Total:	$427,975

D. (10 points) Using the minimum thicknesses of d_1 and d_2 allowed in FTE Table 9.7, show how to find d_3. How much would this pavement design cost to construct? Include excavation and earthwork costs at $3/CY.

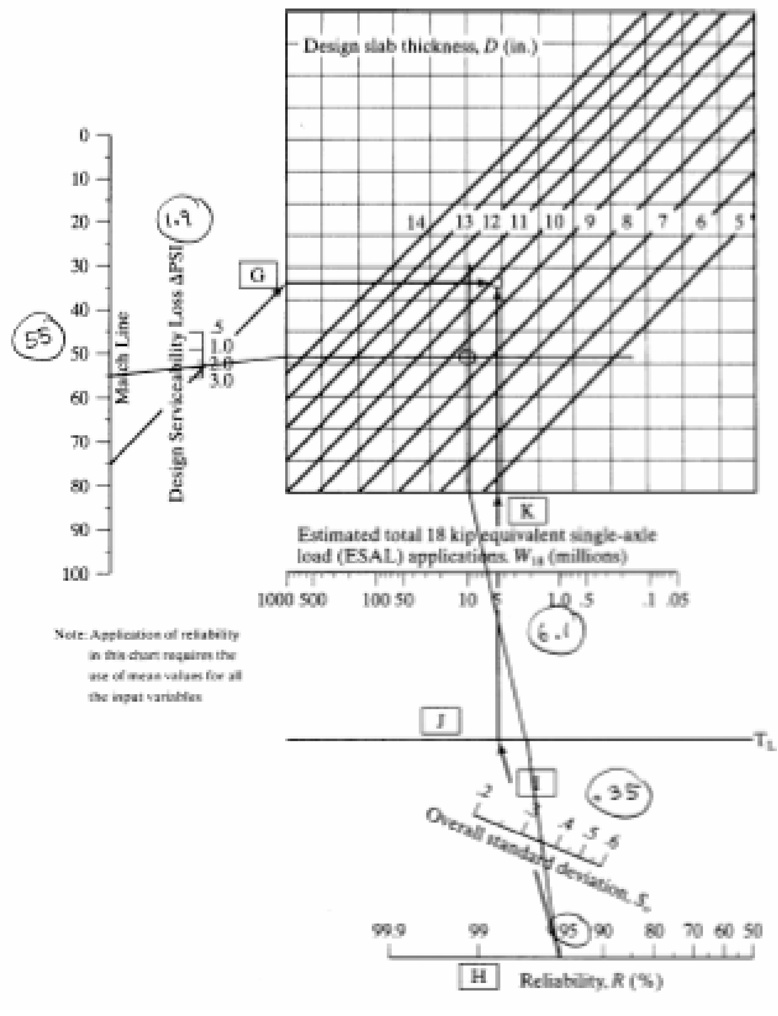
Layer	SN(i)	a(i)	D(i)	D(i) to use	$/la-mi
Surface 2"-4"	3.20	0.43	7.44	3.50	$137,513
Base 4"-10"	2.00	0.13	15.35	6.00	$ 34,693
Subbase 4"-10"	4.22	0.09	46.83	47.00	$124,656
Excavation				56.50	$ 33,147
				Total:	$330,009



3. (20 points) **Rigid pavement design.** S'_c = 926 psi, J = 3.2, $E_c = 4.1*10^6$ psi, k = 100 pci, and C_d = 1.0. Using the design charts, the concrete slab must be (approximately) 8.2" thick. Round up to 8.5".



4.1
Concrete elastic modulus, E_c
(10^6 lb/in.^{2})
7
6
5
4
3
B
C
A
800 500
100
50
10
Effective Modulus of Subgrade Reaction, k (lb/in.^{3})
926
Mean Concrete Modulus of Rupture, S'_c (lb/in.^{2})
1200
1100
1000
900
800
700
600
500
T_L
D
Load transfer coefficient, J
4.5
4.0
3.5
3.0
2.5
2.2
3.2
T_L
E
Drainage coefficient, C_d
1.3
1.1
0.9
0.7
0.6
1.0
Match Line
0
10
20
30
40
50
60
70
80
90
100
55
F



Design slab thickness, D (in.)
14
13
12
11
10
9
8
7
6
5
Match Line
0
10
20
30
40
50
60
70
80
90
100
55
Design Serviceability Loss ΔPSI
1.9
.5
1.0
2.0
3.0
G
K
Estimated total 18 kip equivalent single-axle load (ESAL) applications, W_{18} (millions)
1000 500
100 50
10
5
1.0
.5
.1
.05
6.1
Note: Application of reliability in this chart requires the use of mean values for all the input variables
J
T_L
I
.35
Overall standard deviation, S_o
.2
.3
.4
.5
.6
99.9
99
95
90
80
70
60
50
H
Reliability, R (%)