The Cooper Union for the Advancement of Science and Art

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
INTRODUCTION TO GEOTECHNICAL ENGINEERING LABORATORY

PART 2

SOIL SAMPLE PROPERTIES FROM MANALAPAN, NJ

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Contents

List of Tables

List of Figures

1 Summary of Design

Effective road design takes into account both load capacity and construction costs. The load to which the highway is subjected is determined by the expected traffic the highway will see; to find this, it is necessary to use vehicle axel loads and the number of vehicles per day. The load is supported by the layers comprising the highway: asphalt, base, subbase, and subgrade. With the given options for base and subbase soils as well as the option to use geogrids, it is beneficial to perform calculations for all permutations of the highway layers, to determine the most economical construction design.

With the given load case, highway length and width, and location/available subgrade soil, it is found that the most economical design uses an asphalt layer 9 inches thick and a base layer 6 inches thick. No subbase course is necessary at this location, as the subgrade is found to be strong enough to act as the subbase; consequently, less soil must be hauled to the construction site. The base course uses Soil 3a, without geogrids for a total cost of $1,352,592.59. Were geogrids to be used for this design, it would save $414,197.53 in hauling costs, but the geogrids would cost $586,666.67, resulting in an overall higher project cost. Pumping criteria between the base and subgrade layers were checked, and are met. The final design runs a total cost of $7,219,259.26.

2 Most Economical Design

Base Soil Chosen	3a
CBR	70
Asphalt Modulus (psi)	350000
Base Modulus (psi)	27500
Asphalt Flexural Coefficient	0.39
Asphalt Modifying Structural Layer Coefficient	1
Asphalt Thickness (in)	9
Base Flexural Coefficient	0.13
Base Modifying Structural Layer Coefficient	0.9
Base Thickness (in)	6

Table 1: Final Design Properties

Range of Dry Densities (g)		**Range of Water Content(%)**	
$\gamma_{\max}$	γ at $D_r = 75\%$	**Optimum**	ω **at** $D_r = 75\%$
96.13	110.7	8.55	14.6

Table 2: Subgrade Compaction Control

Maximum Dry Density (pcf)	126
Minimum Dry Density (pcf)	96
Natural Dry Density in Borrow Area (pcf)	121
Bulked Dry Density (pcf)	96

Table 3: Unit Weights of Base and Sub-Base Course Material

Compacting Cost $\left(\$/\mathrm{yd}^3\right)$	2.25
Hauling Cost $\left(\$/\mathrm{yd}^3\right)$	20
Volume of Borrow Area, V_b	1.008
Volume in Hauling Vehicle, V_{hv}	1.271
Excavation and Compaction Costs without Geogrid	$110,000.00
Excavation and Compaction Costs with Geogrid	$73,333.33
Total Hauling Volume $\left(\mathrm{yd}^3\right)$	62129.63
Number of Trucks	6213
Net Hauling Cost with Geogrid ($/yd)	1,242,592.59
Net Hauling Cost without Geogrid ($/yd)	828,395.06

Table 4: Cost Estimate for Hauling and Compacting Sub-Base and Base Course materials Based on 1 yd^3 of Compacted Sub-Base and Base Course

3 Data and Calculations

As seen in *Table 5*, the CBR, Modulus of Elasticity (E), Structural Layer Coefficient (A_i), Modification Factor (M_i), and design structural number (SN_i^*) are given for all soil options that are used in the design of flexible pavement. The structural number was found using Wolfram Alpha and the structural number equation in *Equation 1* with a given standard normal deviate (Z_r) of -1.282, a level of 90% reliability, as seen in *Table 26*, and an overall standard deviation (S_0) of 0.35, a ΔPSI of 1.7 and a W_{18} of 24266603 Equivalent Single Axial Loads.

	Soil #	**CBR @ 90% D_r**	**E (ksi)**	**A_i**	**M_i**	**SN_i^***
Asphalt	N/A	N/A	350	0.39	N/A	N/A
Base	1	80	28.5	0.134	0.9	3.51
	1a	85	29	0.136	0.9	3.51
	2	75	28	0.132	0.9	3.51
	3	70	27.5	0.13	0.9	3.51
	3a	70	27.5	0.13	0.9	3.51
Subgrade	GP-GM	8	12	N/A	N/A	4.12

Table 5: Soil Properties of Used Asphalt, Base, and Subgrade

No subbase was used for the design, negative thicknesses (D_3) were obtained, meaning that the minimum required thickness of 0 inches is adequate. This can be seen in *Table 12* through *Table 16*. This means that the modulus of elasticity of the existing subgrade is adequate to serve as the subbase. Based off of this, the thickness of the base can be recalculated, as seen in *Table 17*. Since no subbase was used, *Table 19* utilizes six possible asphalt and base combinations that meet the required load capacity. The thickness of asphalt is determined in *Table 6*. While *Table 7* through *Table 11* show the cases for base thickness using different subbases; they were not used for any final design considerations. *Figure 2* in the appendix shows how to find the base thickness with the geogrid based on unreinforced base thickness.

Base Soil #	**Asphalt Thickness D_1 (in)**	**Base Thickness D_2 (in)**	**Base Thickness with Geogrid (in)**
1	9	6	4
1a	9	6	4
2	9	6	4
3	9	6	4
3a	9	6	4

Table 6: Calculated Thickness Values for Asphalt

Base Soil Number 1							
Subbase Soil #	SN_2	A_2	M_2	**Calculated** D_2 **(in)**	**Min.** D_2 **(in)**	D_2 **(in)**	SN_2^*
1	3.898	0.134	0.9	3.221	6	6	0.724
1a	3.876	0.134	0.9	3.037	6	6	0.724
2	3.914	0.134	0.9	3.346	6	6	0.724
3	3.952	0.134	0.9	3.666	6	6	0.724
3a	3.952	0.134	0.9	3.666	6	6	0.724
4	3.974	0.134	0.9	3.843	6	6	0.724
5	3.992	0.134	0.9	3.995	6	6	0.724
6	4.010	0.134	0.9	4.147	6	6	0.724
7	4.028	0.134	0.9	4.299	6	6	0.724
9	4.047	0.134	0.9	4.451	6	6	0.724
9a	4.065	0.134	0.9	4.603	6	6	0.724
10	4.083	0.134	0.9	4.755	6	6	0.724

Table 7: Calculated Base Thickness Values for Base Soil Number 1 using Each Subbase

Base Soil Number 1a							
Subbase Soil #	SN_2	A_2	M_2	**Calculated** D_2 **(in)**	**Min.** D_2 **(in)**	D_2 **(in)**	SN_2^*
1	3.898	0.136	0.9	3.174	6	6	0.734
1a	3.876	0.136	0.9	2.992	6	6	0.734
2	3.914	0.136	0.9	3.297	6	6	0.734
3	3.952	0.136	0.9	3.612	6	6	0.734
3a	3.952	0.136	0.9	3.612	6	6	0.734
4	3.974	0.136	0.9	3.787	6	6	0.734
5	3.992	0.136	0.9	3.937	6	6	0.734
6	4.010	0.136	0.9	4.086	6	6	0.734
7	4.028	0.136	0.9	4.236	6	6	0.734
9	4.047	0.136	0.9	4.386	6	6	0.734
9a	4.065	0.136	0.9	4.535	6	6	0.734
10	4.083	0.136	0.9	4.685	6	6	0.734

Table 8: Calculated Base Thickness Values for Base Soil Number 1a using Each Subbase

Base Soil Number 2							
Subbase Soil #	SN_2	A_2	M_2	**Calculated** D_2 **(in)**	**Min.** D_2 **(in)**	D_2 **(in)**	SN_2^*
1	3.898	0.132	0.9	3.270	6	6	0.713
1a	3.876	0.132	0.9	3.083	6	6	0.713
2	3.914	0.132	0.9	3.397	6	6	0.713
3	3.952	0.132	0.9	3.722	6	6	0.713
3a	3.952	0.132	0.9	3.722	6	6	0.713
4	3.974	0.132	0.9	3.902	6	6	0.713
5	3.992	0.132	0.9	4.056	6	6	0.713
6	4.010	0.132	0.9	4.210	6	6	0.713
7	4.028	0.132	0.9	4.364	6	6	0.713
9	4.047	0.132	0.9	4.519	6	6	0.713
9a	4.065	0.132	0.9	4.673	6	6	0.713
10	4.083	0.132	0.9	4.827	6	6	0.713

Table 9: Calculated Base Thickness Values for Base Soil Number 2 using Each Subbase

Base Soil Number 3							
Subbase Soil #	SN_2	A_2	M_2	**Calculated** D_2 **(in)**	**Min.** D_2 **(in)**	D_2 **(in)**	SN_2^*
1	3.898	0.13	0.9	3.320	6	6	0.702
1a	3.876	0.13	0.9	3.130	6	6	0.702
2	3.914	0.13	0.9	3.449	6	6	0.702
3	3.952	0.13	0.9	3.779	6	6	0.702
3a	3.952	0.13	0.9	3.779	6	6	0.702
4	3.974	0.13	0.9	3.962	6	6	0.702
5	3.992	0.13	0.9	4.118	6	6	0.702
6	4.010	0.13	0.9	4.275	6	6	0.702
7	4.028	0.13	0.9	4.431	6	6	0.702
9	4.047	0.13	0.9	4.588	6	6	0.702
9a	4.065	0.13	0.9	4.745	6	6	0.702
10	4.083	0.13	0.9	4.901	6	6	0.702

Table 10: Calculated Base Thickness Values for Base Soil Number 3 using Each Subbase

Base Soil Number 3a							
Subbase Soil #	SN_2	A_2	M_2	**Calculated D_2 (in)**	**Min. D_2 (in)**	**D_2 (in)**	SN_2^*
1	3.898	0.130	0.9	3.320	6	6	0.702
1a	3.876	0.130	0.9	3.130	6	6	0.702
2	3.914	0.130	0.9	3.449	6	6	0.702
3	3.952	0.130	0.9	3.779	6	6	0.702
3a	3.952	0.130	0.9	3.779	6	6	0.702
4	3.974	0.130	0.9	3.962	6	6	0.702
5	3.992	0.130	0.9	4.118	6	6	0.702
6	4.010	0.130	0.9	4.275	6	6	0.702
7	4.028	0.130	0.9	4.431	6	6	0.702
9	4.047	0.130	0.9	4.588	6	6	0.702
9a	4.065	0.130	0.9	4.745	6	6	0.702
10	4.083	0.130	0.9	4.901	6	6	0.702

Table 11: Calculated Base Thickness Values for Base Soil Number 3a using Each Subbase

Base Soil Number 1							
Subbase Soil #	SN_3	A_3	M_3	**Calculated D_3 (in)**	**Min. D_3 (in)**	**D_3 (in)**	SN_3^*
1	4.122	0.135	0.9	-0.922	0	0	0
1a	4.122	0.137	0.9	-0.908	0	0	0
2	4.122	0.133	0.9	-0.936	0	0	0
3	4.122	0.130	0.9	-0.957	0	0	0
3a	4.122	0.130	0.9	-0.957	0	0	0
4	4.122	0.108	0.9	-1.152	0	0	0
5	4.122	0.100	0.9	-1.244	0	0	0
6	4.122	0.128	0.9	-0.972	0	0	0
7	4.122	0.129	0.9	-0.965	0	0	0
9	4.122	0.095	0.9	-1.310	0	0	0
9a	4.122	0.115	0.9	-1.082	0	0	0
10	4.122	0.120	0.9	-1.037	0	0	0

Table 12: Calculated Subbase Thickness Values for Base Soil Number 1 using Each Subbase

Base Soil Number 1a							
Subbase Soil #	SN_3	A_3	M_3	**Calculated** D_3 **(in)**	**Min.** D_3 **(in)**	D_3 **(in)**	SN_3^*
1	4.122	0.135	0.9	-1.011	0	0	0
1a	4.122	0.137	0.9	-0.996	0	0	0
2	4.122	0.133	0.9	-1.026	0	0	0
3	4.122	0.130	0.9	-1.050	0	0	0
3a	4.122	0.130	0.9	-1.050	0	0	0
4	4.122	0.108	0.9	-1.263	0	0	0
5	4.122	0.100	0.9	-1.364	0	0	0
6	4.122	0.128	0.9	-1.066	0	0	0
7	4.122	0.129	0.9	-1.058	0	0	0
9	4.122	0.095	0.9	-1.436	0	0	0
9a	4.122	0.115	0.9	-1.186	0	0	0
10	4.122	0.120	0.9	-1.137	0	0	0

Table 13: Calculated Subbase Thickness Values for Base Soil Number 1a using Each Subbase

Base Soil Number 2							
Subbase Soil #	SN_3	A_3	M_3	**Calculated** D_3 **(in)**	**Min.** D_3 **(in)**	D_3 **(in)**	SN_3^*
1	4.122	0.135	0.9	-0.833	0	0	0
1a	4.122	0.137	0.9	-0.821	0	0	0
2	4.122	0.133	0.9	-0.845	0	0	0
3	4.122	0.13	0.9	-0.865	0	0	0
3a	4.122	0.13	0.9	-0.865	0	0	0
4	4.122	0.108	0.9	-1.041	0	0	0
5	4.122	0.1	0.9	-1.124	0	0	0
6	4.122	0.128	0.9	-0.878	0	0	0
7	4.122	0.129	0.9	-0.872	0	0	0
9	4.122	0.095	0.9	-1.184	0	0	0
9a	4.122	0.115	0.9	-0.978	0	0	0
10	4.122	0.12	0.9	-0.937	0	0	0

Table 14: Calculated Subbase Thickness Values for Base Soil Number 2 using Each Subbase

Base Soil Number 3							
Subbase Soil #	SN_3	A_3	M_3	**Calculated D_3 (in)**	**Min. D_3 (in)**	**D_3 (in)**	SN_3^*
1	4.122	0.135	0.9	-0.744	0	0	0
1a	4.122	0.137	0.9	-0.733	0	0	0
2	4.122	0.133	0.9	-0.755	0	0	0
3	4.122	0.130	0.9	-0.773	0	0	0
3a	4.122	0.130	0.9	-0.773	0	0	0
4	4.122	0.108	0.9	-0.930	0	0	0
5	4.122	0.100	0.9	-1.004	0	0	0
6	4.122	0.128	0.9	-0.785	0	0	0
7	4.122	0.129	0.9	-0.779	0	0	0
9	4.122	0.095	0.9	-1.057	0	0	0
9a	4.122	0.115	0.9	-0.873	0	0	0
10	4.122	0.120	0.9	-0.837	0	0	0

Table 15: Calculated Subbase Thickness Values for Base Soil Number 3 using Each Subbase

Base Soil Number 3a							
Subbase Soil #	SN_3	A_3	M_3	**Calculated D_3 (in)**	**Min. D_3 (in)**	**D_3 (in)**	SN_3^*
1	4.122	0.135	0.9	-0.744	0	0	0
1a	4.122	0.137	0.9	-0.733	0	0	0
2	4.122	0.133	0.9	-0.755	0	0	0
3	4.122	0.130	0.9	-0.773	0	0	0
3a	4.122	0.130	0.9	-0.773	0	0	0
4	4.122	0.108	0.9	-0.930	0	0	0
5	4.122	0.100	0.9	-1.004	0	0	0
6	4.122	0.128	0.9	-0.785	0	0	0
7	4.122	0.129	0.9	-0.779	0	0	0
9	4.122	0.095	0.9	-1.057	0	0	0
9a	4.122	0.115	0.9	-0.873	0	0	0
10	4.122	0.120	0.9	-0.837	0	0	0

Table 16: Calculated Subbase Thickness Values for Base Soil Number 3a using Each Subbase

Base Soil #	SN_2^{**}	A_2	M_2	Calculated D_2 (in)	Min. D_2 (in)	D_2	SN_2^*
1	4.1216	0.134	0.9	5.071	6	6	0.724
1a	4.1216	0.136	0.9	4.997	6	6	0.734
2	4.1216	0.132	0.9	5.148	6	6	0.713
3	4.1216	0.130	0.9	5.227	6	6	0.702
3a	4.1216	0.130	0.9	5.227	6	6	0.702

Table 17: Recalculated Thickness Values for Base Soils Using Subgrade as the Subbase

Base Soil #	Volume of Base Soil (yd^3)	Volume Hauled (yd^3)	Truck Loads
1	48888.89	62857.14	6286
1a	48888.89	64871.79	6488
2	48888.89	64862.49	6487
3	48888.89	64197.53	6420
3a	48888.89	62129.63	6213

Table 18: Base Course Soil Volume Required (without Geogrid)

Base Soil #	Volume of Base Soil (yd^3)	Volume Hauled (yd^3)	Truck Loads
1	32592.59	41904.76	4191
1a	32592.59	43247.86	4326
2	32592.59	43241.66	4325
3	32592.59	42798.35	4280
3a	32592.59	41419.75	4142

Table 19: Base Course Soil Volume Required (with Geogrid)

Soil #	$\gamma_{d\ max}$ (pcf)	$\gamma_{d\ min}$ (pcf)	$\gamma_{d\ nat}$ (pcf)	$\gamma_{d\ bulk}$ (pcf)	$\gamma_{d\ 90}$ (pcf)	V_b	V_{hv}	Compaction Cost ($/yd^3)	Hauling Cost ($/yd^3)
1	138	113	129	105	135	1.047	1.286	2.40	20
1a	141	116	127	104	138	1.087	1.327	2.40	20
2	137	112	127	101	134	1.055	1.327	2.30	20
3	133	108	120	99	130	1.083	1.313	2.25	20
3a	126	96	121	96	122	1.008	1.271	2.25	20

Table 20: Calculations of Volume in Borrow Area and Volume in Hauling Vehicle

Highway Length (miles)	10
Highway Width (ft)	50
Standard Deviation, S_0	0.35
Design Servicability Loss, ΔPSI	1.7
Standard Deviate, Z_R	-1.282
18-kip ESAL, W_{18}	24266603
Cost of Asphalt (\$/yd^3)	80
Cost of Geogrid (\$/yd^2)	2
Cost of Geotextile (\$/yd^2)	3
Hauling Truck Capacity (yd^3)	10

Table 21: Given Parameters

Soil #	Asphalt Thickness (in)	Asphalt Volume (yd^3)	Asphalt Cost (\$)
1	9	73333.33	$5,866,666.67
1a	9	73333.33	$5,866,666.67
2	9	73333.33	$5,866,666.67
3	9	73333.33	$5,866,666.67
3a	9	73333.33	$5,866,666.67

Table 22: Necessary Volume and Cost of Asphalt

Base Soil #	D_{15} (mm)	D_{85} (mm)	C_u (hydrometer)	C_u (no hydrometer)	Pass	Geotextile Cost
1	5.50	25	205.88	4.21	NO PASS	$880,000
1a	10.00	25	205.88	4.21	NO PASS	$880,000
2	7.50	25	205.88	4.21	NO PASS	$880,000
3	0.13	25	205.88	4.21	PASS	N/A
3a	2.50	25	205.88	4.21	PASS	N/A

Table 23: Pumping Criteria

Base Soil #	Excavation	Hauling	Asphalt	Geotextile	Total
1	$117,333.33	$1,257,142.86	$5,866,666.67	$880,000	$8,121,143.86
1a	$117,333.33	$1,297,435.90	$5,866,666.67	$880,000	$8,161,435.90
2	$112,444.44	$1,297,249.72	$5,866,666.67	$880,000	$8,156,362.84
3	$110,000.00	$1,283,950.62	$5,866,666.67	$0	$7,260,620.28
3a	$110,000.00	$1,242,592.59	$5,866,666.67	$0	$7,219,259.26

Table 24: Total Costs (without Geogrid)

Base Soil #	Excavation	Hauling	Asphalt	Geogrid	Geotextile	Total
1	$78,222.22	$838,095.24	$5,866,666.67	$586,666.67	$880,000	$8,249,650.79
1a	$78,222.22	$864,957.26	$5,866,666.67	$586,666.67	$880,000	$8,276,512.82
2	$74,962.96	$864,833.15	$5,866,666.67	$586,666.67	$880,000	$8,273,129.45
3	$73,333.33	$855,967.08	$5,866,666.67	$586,666.67	$0	$7,382,633.74
3a	$73,333.33	$828,395.06	$5,866,666.67	$586,666.67	$0	$7,355,061.73

Table 25: Total Costs (with Geogrid)

4 Sample Calculations

4.1 Structure Number

The structure number is calculated using *Equation 1*.

$$\log(W_{18}) = Z_R \times S_0 + 9.36 \times \log(SN+1) - 0.2 + \frac{\log\left(\frac{\Delta PSI}{4.2-2.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log(M_R) - 8.07 \tag{1}$$

$$\log(24266603) = -1.282 \times 0.35 + 9.36 \times \log(SN+1) - 0.2 + \frac{\log\left(\frac{1.7}{4.2-2.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log(12000) - 8.07$$

$$SN = \boxed{4.122}$$

4.2 Dry Weight at a Relative Density of 90%

The dry weight at a relative density of 90% is calculated using *Equation 2*.

$$\gamma_{d\,90} = \frac{\gamma_{d\text{ max}} \times \gamma_{d\text{ min}}}{\gamma_{d\text{ max}} - D_r \times (\gamma_{d\text{ max}} - \gamma_{d\text{ min}})} \tag{2}$$

$$\gamma_{d\,90} = \frac{138\text{ pcf} \times 113\text{ pcf}}{138\text{ pcf} - 0.9 \times (138\text{ pcf} - 113\text{ pcf})} = \boxed{135\text{ pcf}}$$

4.3 Asphalt Layer

4.3.1 Thickness

The thickness of the asphalt layer is calculated using *Equation 3*. A value less than 9 inches means that the minimum thickness of 9 inches should be used.

$$D_1 = \frac{SN_1}{A_1} \tag{3}$$

$$D_1 = \frac{3.36}{0.39} = \boxed{8.62\text{ in}}$$

4.3.2 Design Structure Number

The design structure number of the asphalt layer is calculated using *Equation 4*.

$$SN_1^* = A_1 \times D_1 \tag{4}$$

$$SN_1^* = 0.39 \times 9 \text{ in} = \boxed{3.51}$$

4.3.3 Cost

The cost of the asphalt layer (C_{at}) is calculated using *Equation 5*, where C_a is the asphalt cost.

$$C_{at} = A \times D_1 \times C_a \tag{5}$$

$$C_{at} = 293333.33 \text{ yd}^2 \times 9 \text{ in} \times \frac{1 \text{ yd}}{36 \text{ in}} \times 80 \text{ \$/yd}^3 = \boxed{\$5866666.67}$$

4.4 Base Layer

4.4.1 Thickness

The thickness of the base layer is calculated using *Equation 6*. A value less than 6 inches means that the minimum thickness of 6 inches should be used.

$$D_2 = \frac{SN_2 - SN_1^*}{A_2 \times M_2} \tag{6}$$

$$D_2 = \frac{3.9 - 3.51}{0.134 \times 0.9} = \boxed{3.22 \text{ in}}$$

4.4.2 Design Structure Number

The design structure number of the base layer is calculated using *Equation 7*.

$$SN_2^* = A_2 \times D_2 \times M_2 \tag{7}$$

$$SN_2^* = 0.134 \times 6 \text{ in} \times 0.9 = \boxed{0.724}$$

4.4.3 Volume of Borrow Area

The volume of borrow area is calculated using *Equation 8*.

$$V_b = \frac{\gamma_{d\,90}}{\gamma_{d \text{ nat}}} \tag{8}$$

$$V_b = \frac{135}{129} = \boxed{1.05}$$

4.4.4 Hauling Vehicle Volume

The hauling vehicle volume is calculated using *Equation 9*.

$$V_{hv} = \frac{\gamma_{d\,90}}{\gamma_{d\text{ bulk}}} \tag{9}$$

$$V_{hv} = \frac{135}{105} = \boxed{1.29}$$

4.4.5 Excavation Cost

The excavation cost (C_e) is calculated using *Equation 10*, where C_c is the compacting cost.

$$C_e = A \times D_2 \times C_c \tag{10}$$

$$C_e = 293333.33 \text{ yd}^2 \times 6 \text{ in} \times \frac{1 \text{ yd}}{36 \text{ in}} \times 2.4 \text{ \$/yd}^3 = \boxed{\$117,333.33}$$

4.4.6 Total Hauling Cost

The total hauling cost (C_{ht}) is calculated using *Equation 11*, where C_h is the hauling cost.

$$C_{ht} = A \times D_2 \times V_{hv} \times C_h \tag{11}$$

$$C_{ht} = 293333.33 \text{ yd}^2 \times 6 \text{ in} \times \frac{1 \text{ yd}}{36 \text{ in}} \times 1.29 \times 20 \text{ \$/yd}^3 = \boxed{\$1,257,142.86}$$

4.4.7 Total Number of Trucks

The total number of trucks (N_t) is calculated using *Equation 12*.

$$N_t = A \times D_2 \times V_{hv} \times \frac{1}{10} \tag{12}$$

$$N_t = 293333.33 \text{ yd}^2 \times 6 \text{ in} \times \frac{1 \text{ yd}}{36 \text{ in}} \times 1.29 \times \frac{1 \text{ truck}}{10 \text{ yd}^3} = \boxed{6286 \text{ trucks}}$$

4.5 Subbase Layer

4.5.1 Thickness

The thickness of the subbase layer is calculated using *Equation 13.* A negative value means that no subbase is required, therefore the thickness is 0 inches.

$$D_3 = \frac{SN_3 - (SN_2^* + SN_1^*)}{A_3 \times M_3} \tag{13}$$

$$D_3 = \frac{4.122 - (0.724 + 3.51)}{0.135 \times 0.9} = \boxed{-0.922 \text{ in}}$$

4.5.2 Design Structure Number

The design structure number of the subbase layer is calculated using *Equation 14.*

$$SN_3^* = A_3 \times D_3 \times M_3 \tag{14}$$

$$SN_3^* = 0.135 \times 0 \text{ in} \times 0.9 = \boxed{0}$$

4.6 Geogrid Cost

The geogrid cost (C_g) is calculated using *Equation 15*, where C_{gg} is the given geogrid cost per square yard.

$$C_g = A \times C_{gg} \tag{15}$$

$$C_g = 293333.33 \text{ yd}^2 \times 2 \text{ \$/yd}^2 = \boxed{\$586,666.67}$$

4.7 Geotextile Cost

The geotextile cost (C_{gt}) is calculated using *Equation 16*, where C_{ggt} is the given geotextile cost per square yard.

$$C_{gt} = A \times C_{ggt} \tag{16}$$

$$C_g = 293333.33 \text{ yd}^2 \times 3 \text{ \$/yd}^2 = \boxed{\$880,000}$$

4.8 Total Cost

The total cost (C_t) is calculated using *Equation 17*, using the geogrid cost if applicable.

$$C_t = C_e + C_{ht} + C_{at} + C_g \tag{17}$$

$$C_t = \$117,333.33 + \$1,257,142.86 + \$5866666.67 + \$0 = \boxed{\$7,241,143.86}$$

5 Appendix

Reliability (%)	**Standard Normal Deviate (Z_R)**
50	0.000
60	-0.253
70	-0.524
75	-0.674
80	-0.841
85	-1.037
90	-1.282
91	-1.34
92	-1.405
93	-1.476
94	-1.555
95	-1.645
96	-1.751
97	-1.881
98	-2.054
99	-2.327
99.9	-3.09
99.99	-3.75

Table 26: Standard Normal Deviates for Various Reliability Levels

Soil #	CBR @ Dr = 90%	γ_d max (pcf)	γ_d min (pcf)	γ_d nat (pcf)	γ_d bulk (pcf)	Compacting Cost ($/yd^3)	Hauling Cost ($/yd^3)
1	80	138	113	129	105	$2.40	$20.00
1a	85	141	116	127	104	$2.40	$20.00
2	75	137	112	127	101	$2.30	$20.00
3	70	133	108	120	99	$2.25	$20.00
3a	70	126	96	121	96	$2.25	$20.00
4	30	124	98	107	90	$1.75	$20.00
5	25	113	91	110	84	$1.65	$20.00
6	50	131	115	119	104	$2.10	$20.00
7	60	129	115	117	101	$2.15	$20.00
9	20	111	87	109	77	$1.65	$20.00
9a	35	128	99	109	91	$1.85	$20.00
10	40	123	106	112	95	$1.90	$20.00

Table 27: Properties of Available Base Course and Subbase Materials

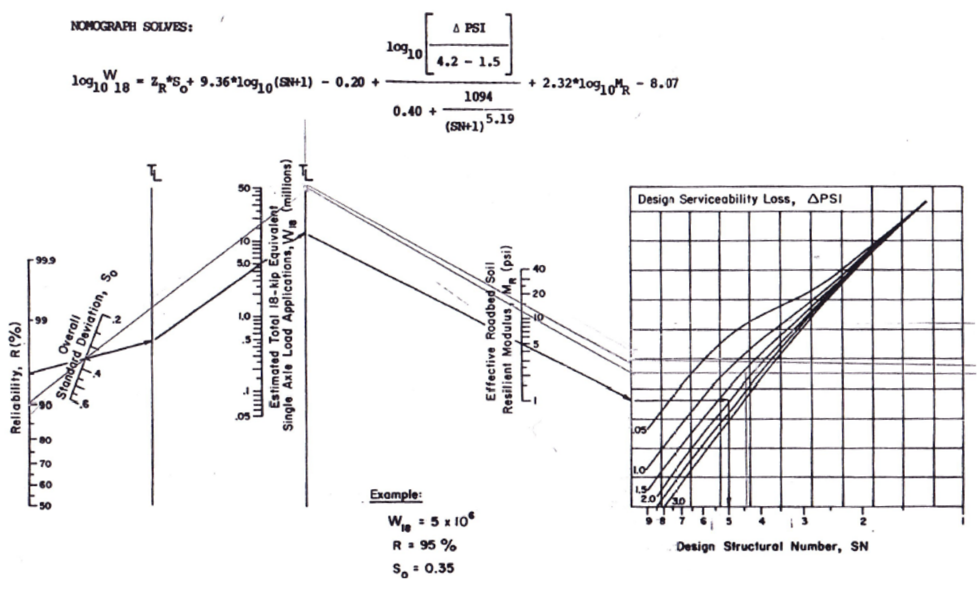

Figure 1: Nomograph and Design Chart For Flexible Pavements

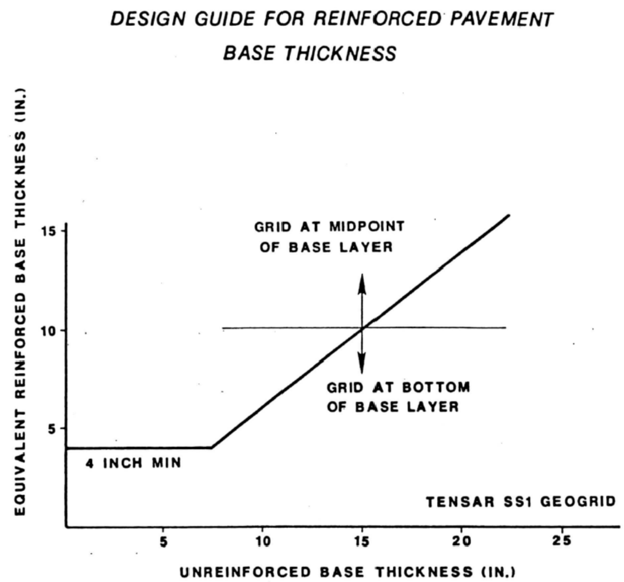

Figure 2: Reinforced Base Layer Thickness Based on Unreinforced Base Layer Thickness