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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Base Modifying Structural Layer Coefficient	-
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Table 1: Final Design Properties

Range of Dry Densities (pcf)		**Range of Water Content(%)**	
γ_{max}	γ at $D_r = 75\%$	**Optimum**	ω **at** $D_r = 75\%$
-	-	-	-

Table 2: Subgrade Compaction Control

Maximum Dry Density (pcf)	-
Minimum Dry Density (pcf)	-
Natural Dry Density in Borrow Area (pcf)	-
Bulked Dry Density (pcf)	-

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

Compacting Cost $\left(\$/\mathrm{yd}^3\right)$	-
Hauling Cost $\left(\$/\mathrm{yd}^3\right)$	-
Volume of Borrow Area, V_b	-
Volume in Hauling Vehicle, V_{hv}	-
Excavation and Compaction Costs ($)	-
Total Hauling Volume $\left(\mathrm{yd}^3\right)$	-
Number of Trucks	-
Net Hauling Cost $(\$/\mathrm{yd})$	-

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

	Soil #	**CBR @ 90% D_r**	***E* (ksi)**	A_i	M_i	SN_i
Asphalt	N/A	-	-	-	-	-
	1	-	-	-	-	-
	1a	-	-	-	-	-
Base	2	-	-	-	-	-
	3	-	-	-	-	-
	3a	-	-	-	-	-
Subgrade	-	-	-	-	-	-

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

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

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	-	-	-	-	-	-	-
1a	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
3a	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
9a	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-

Table 7: Calculated 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	-	-	-	-	-	-	-
1a	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
3a	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
9a	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-

Table 8: Calculated 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	-	-	-	-	-	-	-
1a	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
3a	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
9a	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-

Table 9: Calculated 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	-	-	-	-	-	-	-
1a	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
3a	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
9a	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-

Table 10: Calculated 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	-	-	-	-	-	-	-
1a	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
3a	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
9a	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-

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

Base Soil Number 1						
Subbase Soil #	A_3	M_3	Calculated D_3 (in)	Min. D_3 (in)	D_3 (in)	SN_3^*
1	-	-	-	-	-	-
1a	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
3a	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
9	-	-	-	-	-	-
9a	-	-	-	-	-	-
10	-	-	-	-	-	-

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

Base Soil Number 1a						
Subbase Soil #	A_3	M_3	**Calculated D_3 (in)**	**Min. D_3 (in)**	**D_3 (in)**	SN_3^*
1	-	-	-	-	-	-
1a	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
3a	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
9	-	-	-	-	-	-
9a	-	-	-	-	-	-
10	-	-	-	-	-	-

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

Base Soil Number 2						
Subbase Soil #	A_3	M_3	**Calculated D_3 (in)**	**Min. D_3 (in)**	**D_3 (in)**	SN_3^*
1	-	-	-	-	-	-
1a	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
3a	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
9	-	-	-	-	-	-
9a	-	-	-	-	-	-
10	-	-	-	-	-	-

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

Base Soil Number 3						
Subbase Soil #	A_3	M_3	**Calculated D_3 (in)**	**Min. D_3 (in)**	**D_3 (in)**	SN_3^*
1	-	-	-	-	-	-
1a	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
3a	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
9	-	-	-	-	-	-
9a	-	-	-	-	-	-
10	-	-	-	-	-	-

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

Base Soil Number 3a						
Subbase Soil #	A_3	M_3	**Calculated D_3 (in)**	**Min. D_3 (in)**	**D_3 (in)**	SN_3^*
1	-	-	-	-	-	-
1a	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
3a	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
9	-	-	-	-	-	-
9a	-	-	-	-	-	-
10	-	-	-	-	-	-

Table 16: Calculated 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	-	-	-	-	-	-	-
1a	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
3a	-	-	-	-	-	-	-

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	-	-	-
1a	-	-	-
2	-	-	-
3	-	-	-
3a	-	-	-

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

Base Soil #	Volume of Base Soil (yd^3)	Volume Hauled (yd^3)	Truck Loads
1	-	-	-
1a	-	-	-
2	-	-	-
3	-	-	-
3a	-	-	-

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)
1	-	-	-	-	-	-	-	-
1a	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
3a	-	-	-	-	-	-	-	-

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}	31425018
Cost of Asphalt ($/yd^3)	80
Cost of Geogrid ($/yd^2)	1.8

Table 21: Given Parameters

Soil #	Asphalt Thickness (in)	Asphalt Volume (yd^3)	Asphalt Cost ($)
1	-	-	-
1a	-	-	-
2	-	-	-
3	-	-	-
3a	-	-	-

Table 22: Necessary Volume and Cost of Asphalt

Base Soil #	Excavation ($)	Hauling ($)	Asphalt ($)	Total ($)
1	-	-	-	-
1a	-	-	-	-
2	-	-	-	-
3	-	-	-	-
3a	-	-	-	-

Table 23: Total Costs (without Geogrid)

Base Soil #	**Excavation ($)**	**Hauling ($)**	**Asphalt ($)**	**Geogrid ($)**	**Total ($)**
1	-	-	-	-	-
1a	-	-	-	-	-
2	-	-	-	-	-
3	-	-	-	-	-
3a	-	-	-	-	-

Table 24: Total Costs (with Geogrid)

4 Sample Calculations

4.1 Structure Number

The structure number is calculated using *Equation 1*.

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

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

4.2 Dry Weight at a Relative Density of 90%

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

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

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

4.3 Asphalt Layer

4.3.1 Thickness

The thickness of the asphalt layer is calculated using *Equation 3*.

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

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

4.3.2 Design Structure Number

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

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

$$SN_1^* = A_1 \times D_1$$

4.3.3 Cost

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

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

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

4.4 Base Layer

4.4.1 Thickness

The thickness of the base layer is calculated using *Equation 6*.

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

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

4.4.2 Design Structure Number

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

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

$$SN_2^* = A_2 \times D_2 \times M_2$$

4.4.3 Volume of Borrow Area

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

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

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

4.4.4 Hauling Vehicle Volume

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

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

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

4.4.5 Excavation Cost

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

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

$$C_e = A \times D_2 \times C_c$$

4.4.6 Total Hauling Cost

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

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

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

4.4.7 Total Number of Trucks

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

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

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

4.5 Subbase Layer

4.5.1 Thickness

The thickness of the subbase layer is calculated using *Equation 13*.

$$D_2 = \frac{SN_2 - (SN_2^* + SN_1^*)}{A_3 \times M_3} \tag{13}$$

$$D_2 = \frac{SN_2 - (SN_2^* + SN_1^*)}{A_3 \times M_3}$$

4.5.2 Design Structure Number

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

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

$$SN_3^* = A_3 \times D_3 \times M_3$$

4.6 Total Cost

The total cost (C_t) is calculated using *Equation 15*.

$$C_t = C_e + C_{ht} + C_{at} \tag{15}$$

$$C_t = C_e + C_{ht} + C_{at}$$