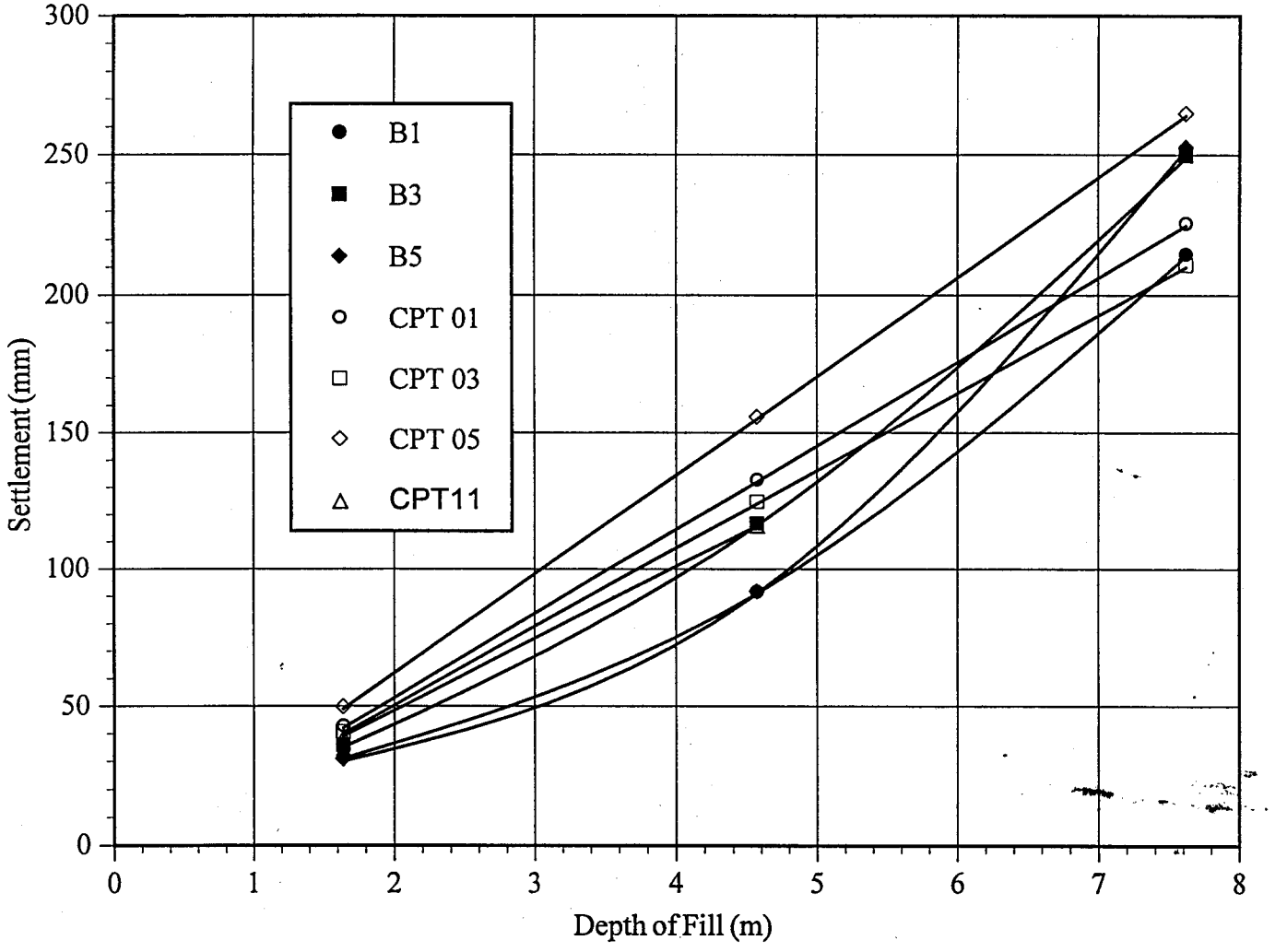
APPENDIX G

Settlement Calculations



SETTLEMENT AS A FUNCTION OF FILL DEPTH BASED ON CONE PENETROMETER TESTING AND LABORATORY ANALYSIS OF SOIL SAMPLES

SETTLEMENT $S_c = C_r \frac{H_o}{1-e_o} \log \frac{\sigma_p'}{\sigma_v'} + C_c \frac{H_o}{1-e_o} \log \frac{\sigma_f'}{\sigma_p'}$

C_r = RECOMPRESSION INDEX

C_c = COMPRESSION INDEX

H_o = INITIAL LAYER THICKNESS

e_o = INITIAL VOID RATIO

σ_v' = IN-SITU EFFECTIVE STRESS

σ_p' = EFFECTIVE PRECONSOLIDATION PRESSURE

σ_f' = FINAL EFFECTIVE PRESSURE AS A RESULT OF APPLIED OVERBURDEN

SETTLEMENT BASED ON CONSOLIDATION TEST RESULTS

Boring # B1: Fill Height = 7.62 m (25 ft)

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.2 to 3.1	1.9	244	0.84	0.035	0.208	1.47	1.2	0.63	0.39	2.1	1.9	62
3.7 to 7.8	4.1	244	0.76	0.0525	0.211	1.38	2.0	1.22	0.98	2.6	2.4	73
9.6 to 16.2	6.6	244	0.71	0.0493	0.18	1.23	2.8	2.4	2.16	3.63	3.4	79
Total Settlement												214

Boring # B1: Fill Height = 4.57 m (15 ft)

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.2 to 3.1	1.9	244	0.84	0.035	0.208	0.88	1.2	0.63	0.39	1.51	1.3	26
3.7 to 7.8	4.1	244	0.76	0.0525	0.211	0.83	2.0	1.22	0.98	2.05	1.8	33
9.6 to 16.2	6.6	244	0.71	0.0493	0.18	0.74	2.8	2.4	2.16	3.14	2.9	32
Total Settlement												91

Boring # B1: Fill Height = 1.64 m (5 ft)

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.2 to 3.1	1.9	244	0.84	0.035	0.208	0.29	1.2	0.63	0.39	0.92	0.7	9
3.7 to 7.8	4.1	244	0.76	0.0525	0.211	0.28	2.0	1.22	0.98	1.5	1.3	13
9.6 to 16.2	6.6	244	0.71	0.0493	0.18	0.25	2.8	2.4	2.16	2.65	2.4	9
Total Settlement												31

SETTLEMENT BASED ON CONSOLIDATION TEST RESULTS

Boring # B3: Fill Height = 7.62 m

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.2 to 4.6	3.4	244	0.84	0.035	0.208	1.47	1.2	0.63	0.386	2.1	1.9	111
4.6 to 7.6	3.0	244	1.09	0.103	0.29	1.38	1.6	1.22	0.976	2.6	2.4	102
8.7 to 11.6	2.9	244	0.73	0.0285	0.173	1.23	2.4	2.1	1.856	3.33	3.1	37
12.5 to 15.4	2.9	244	0.68	0.039	0.186	1.18	3.0	2.76	2.516	3.94	3.7	34
Total Settlement												249

Boring # B3: Fill Height = 4.57 m

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.2 to 4.6	3.4	244	0.84	0.035	0.208	0.88	1.2	0.63	0.386	1.51	1.3	47
4.6 to 7.6	3.0	244	1.09	0.103	0.29	0.83	1.6	1.22	0.976	2.05	1.8	54
8.7 to 11.6	2.9	244	0.73	0.0285	0.173	0.74	2.4	2.1	1.856	2.84	2.6	15
12.5 to 15.4	2.9	244	0.68	0.039	0.186	0.71	3.0	2.76	2.516	3.47	3.2	15
Total Settlement												116

Boring # B3: Fill Height = 1.64 m

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.2 to 4.6	3.4	244	0.84	0.035	0.208	0.29	1.2	0.63	0.386	0.92	0.7	16
4.6 to 7.6	3.0	244	1.09	0.103	0.29	0.28	1.6	1.22	0.976	1.5	1.3	16
8.7 to 11.6	2.9	244	0.73	0.0285	0.173	0.25	2.4	2.1	1.856	2.35	2.1	3
12.5 to 15.4	2.9	244	0.68	0.039	0.186	0.24	3.0	2.76	2.516	3	2.8	3
Total Settlement												35

SETTLEMENT BASED ON CONSOLIDATION TEST RESULTS

Boring # B5: Fill Height = 7.62 m

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.9 to 6.1	5.2	219	1.09	0.0515	0.258	1.47	1.6	0.92	0.701	2.39	2.2	131
6.7 to 9.0	2.3	219	0.85	0.0455	0.215	1.38	2.2	1.52	1.301	2.9	2.7	36
9.6 to 16.2	6.6	219	0.75	0.0285	0.173	1.23	2.4	2.1	1.881	3.33	3.1	85
Total Settlement												252

Boring # B5: Fill Height = 4.57 m

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.9 to 6.1	5.2	219	1.09	0.0515	0.258	0.88	1.6	0.92	0.701	1.8	1.6	43
6.7 to 9.0	2.3	219	0.85	0.0455	0.215	0.83	2.2	1.52	1.301	2.35	2.1	12
9.6 to 16.2	6.6	219	0.75	0.0285	0.173	0.74	2.4	2.1	1.881	2.84	2.6	36
Total Settlement												91

Boring # B5: Fill Height = 1.64 m

Layer Depth (m)	Thickness (m)	Depth to GW (cm)	Void Ratio	Recompression Index, C_r	Compression Index, C_c	$\Delta\sigma$ (kg/cm^2)	σ_p' (kg/cm^2)	σ_v (kg/cm^2)	σ_v' (kg/cm^2)	σ_f (kg/cm^2)	σ_f' (kg/cm^2)	Settlement (mm)
1.9 to 6.1	5.2	219	1.09	0.0515	0.258	0.29	1.6	0.92	0.701	1.21	1.0	19
6.7 to 9.0	2.3	219	0.85	0.0455	0.215	0.28	2.2	1.52	1.301	1.8	1.6	5
9.6 to 16.2	6.6	219	0.75	0.0285	0.173	0.25	2.4	2.1	1.881	2.35	2.1	6
Total Settlement												30

where V is the projection of the load resultant on the axis perpendicular to the footing, and H is the projection of the load resultant on the plan of the footing.

* Footing shape:

Tand (1986) recommends to use Hansen's (1961) shape factor:

$$s = \frac{1}{1.2}\left(1 + 0.2\frac{B'}{L'}\right) \qquad (7.29)$$

where B' and L' are defined in Fig. 7.3a.

* Base inclination:

Vesic (1975) proposed:

$$b = 1 - 0.39\upsilon \qquad (7.30)$$

where υ is the base inclination angle in radians as defined in Fig. 7.3b.

* Ground inclination:

Vesic (1975) proposed:

$$g = 1 - 0.39\beta \qquad (7.31)$$

where β is ground inclination angle in radians as defined in Fig. 7.3b.

* Depth of embedment:

Tand's formula already incorporates the effect of the depth of embedment through the factor R_k (Fig. 7.9).

7.1.2.6 Settlement: Sanglerat's (1972) step-by-step procedure

* Settlement equation:

Sanglerat proposed:

$$S = \sum_{1}^{n} H_o \frac{\Delta\sigma}{\alpha \bar{q}_c} \qquad (7.32)$$

where:

S = total settlement, including short term and long term settlement.

H_o = expected change in stress at the middle of a soil layer.

α = soil compressibility coefficient.

$\bar{q}_c$ = average tip resistance for a soil layer.

* Procedure:

1. Prepare a table with the following headings.

Table 7.1 - Sanglerat's correlation for M, $M = \alpha \cdot q_c$
(after Costet and Sanglerat, 1975)

q_c (bar)	α	Soil type
$q_c < 7$ $7 < q_c < 20$ $q_c > 20$	$3 < \alpha < 8$ $2 < \alpha < 5$ $1 < \alpha < 2.5$	Clay of low plasticity (CL)
$q_c > 20$ $q_c < 20$	$3 < \alpha < 6$ $1 < \alpha < 3$	Silts of low plasticity (ML)
$q_c < 20$	$2 < \alpha < 6$	Highly plastic silts and clays (MH, CH)
$q_c < 12$	$2 < \alpha < 8$	Organic silts (OL)
$q_c < 7$ $50 < w < 100$ $100 < w < 200$ $w > 200$	 $1.5 < \alpha < 4$ $1 < \alpha < 1.5$ $0.4 < \alpha < 1$	Peat and organic clay (P_t, OH)
$20 < q_c < 30$	$2 < \alpha < 4$	Chalk
$q_c < 50$ $q_c > 100$	$\alpha = 2$ $\alpha = 1.5$	Sand

SETTLEMENT BASED ON CONE PENETROMETER TEST RESULTS

CPT # 01: Fill Height = 7.62 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	0.9	3438	3	165	21	144	1.00	144	13
2	0.9	1111	3.5	165	21	144	0.98	141.12	33
3	0.6	4146	1.5	165	21	144	0.96	138.24	14
4	4.1	1839	4	165	21	144	0.94	135.36	75
5	0.3	6263	1.5	165	21	144	0.90	129.6	4
6	9.0	2911	4.5	165	21	144	0.87	125.28	86
Total Settlement									225

CPT # 01: Fill Height = 4.57 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q (kPa)	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	0.9	3438	3	109	21	86.4	1.00	86.4	8
2	0.9	1111	3.5	109	21	86.4	0.98	84.672	20
3	0.6	4146	1.5	109	21	86.4	0.95	82.08	8
4	4.1	1839	4	109	21	86.4	0.92	79.488	44
5	0.3	6263	1.5	109	21	86.4	0.87	75.168	2
6	9.0	2911	4.5	109	21	86.4	0.84	72.576	50
Total Settlement									132

CPT # 01: Fill Height = 1.64 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q (kPa)	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	0.9	3438	3	52	21	28.8	1.00	28.8	3
2	0.9	1111	3.5	52	21	28.8	0.97	27.936	7
3	0.6	4146	1.5	52	21	28.8	0.93	26.784	3
4	4.1	1839	4	52	21	28.8	0.89	25.632	14
5	0.3	6263	1.5	52	21	28.8	0.83	23.904	1
6	9.0	2911	4.5	52	21	28.8	0.77	22.176	15
Total Settlement									42

SETTLEMENT BASED ON CONE PENETROMETER TEST RESULTS

CPT # 03: Fill Height = 7.62 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	6.4	1460	4.5	165	21	144	0.98	141.12	137
2	0.9	12500	1.5	165	21	144	0.90	129.6	6
3	3.0	2180	4.5	165	21	144	0.87	125.28	38
4	0.6	19900	1.5	165	21	144	0.84	120.96	2
5	3.4	3361	4.5	165	21	144	0.80	115.2	26
Total Settlement									210

CPT # 03: Fill Height = 4.57 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q (kPa)	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	6.4	1460	4.5	109	21	86.4	0.98	84.672	82
2	0.9	12500	1.5	109	21	86.4	0.89	76.896	4
3	3.0	2180	4.5	109	21	86.4	0.84	72.576	22
4	0.6	19900	1.5	109	21	86.4	0.79	68.256	1
5	3.4	3361	4.5	109	21	86.4	0.74	63.936	14
Total Settlement									124

CPT # 03: Fill Height = 1.64 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q (kPa)	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	6.4	1460	4.5	52	21	28.8	0.98	28.224	27
2	0.9	12500	1.5	52	21	28.8	0.83	23.904	1
3	3.0	2180	4.5	52	21	28.8	0.77	22.176	7
4	0.6	19900	1.5	52	21	28.8	0.70	20.16	0
5	3.4	3361	4.5	52	21	28.8	0.63	18.144	4
Total Settlement									40

SETTLEMENT BASED ON CONE PENETROMETER TEST RESULTS

CPT # 05: Fill Height = 7.62 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	1.7	1781	3	165	21	144	1.00	144	45
2	3.2	1273	4.5	165	21	144	0.98	141.12	79
3	0.6	14700	1.5	165	21	144	0.96	138.24	4
4	2.3	1771	4.5	165	21	144	0.94	135.36	39
5	0.6	13700	1.5	165	21	144	0.90	129.6	4
6	2.9	2719	4	165	21	144	0.87	125.28	33
7	1.5	2750	3.5	165	21	144	0.84	120.96	19
8	2.4	1500	4.5	165	21	144	0.80	115.2	41
Total Settlement									264

CPT # 05: Fill Height = 4.57 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q (kPa)	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	1.7	1781	3	109	21	86.4	1.00	86.4	27
2	3.2	1273	4.5	109	21	86.4	0.98	84.672	47
3	0.6	14700	1.5	109	21	86.4	0.95	82.08	2
4	2.3	1771	4.5	109	21	86.4	0.92	79.488	23
5	0.6	13700	1.5	109	21	86.4	0.89	76.896	2
6	2.9	2719	4	109	21	86.4	0.84	72.576	19
7	1.5	2750	3.5	109	21	86.4	0.79	68.256	11
8	2.4	1500	4.5	109	21	86.4	0.74	63.936	23
Total Settlement									155

CPT # 05: Fill Height = 1.64 m									
Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q (kPa)	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	1.7	1781	3	52	21	28.8	1.00	28.8	9
2	3.2	1273	4.5	52	21	28.8	0.97	27.936	16
3	0.6	14700	1.5	52	21	28.8	0.93	26.784	1
4	2.3	1771	4.5	52	21	28.8	0.89	25.632	7
5	0.6	13700	1.5	52	21	28.8	0.83	23.904	1
6	2.9	2719	4	52	21	28.8	0.77	22.176	6
7	1.5	2750	3.5	52	21	28.8	0.70	20.16	3
8	2.4	1500	4.5	52	21	28.8	0.63	18.144	6
Total Settlement									49

SETTLEMENT BASED ON CONE PENETROMETER TEST RESULTS

CPT # 11: Fill Height = 4.57 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q (kPa)	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	3.5	7660	1.5	109	21	86.4	1.00	86.4	26
2	1.2	1244	4.5	109	21	86.4	0.97	83.808	18
3	0.8	23940	1.5	109	21	86.4	0.94	81.216	2
4	0.8	2394	4	109	21	86.4	0.90	77.76	6
5	2.9	9576	1.5	109	21	86.4	0.85	73.44	15
6	1.2	2011	3.5	109	21	86.4	0.82	70.848	12
7	0.9	28728	1.5	109	21	86.4	0.80	69.12	1
8	1.8	4788	1.5	109	21	86.4	0.77	66.528	17
9	3.5	2872	4	109	21	86.4	0.72	62.208	19
Total Settlement									116

CPT # 11: Fill Height = 1.64 m

Layer #	Layer Thickness H_o (m)	Ave. Tip Resistance q_c (kPa)	Compression. Coefficient. α	Embankment Bearing Pressure q (kPa)	Effective Stress at Fill Base σ' (kPa)	Net Found. Pressure Δp (kPa)	Stress Influence Factor I	Change in Stress $\Delta\sigma$ (kPa)	Settlement (mm)
1	3.5	7660	1.5	52	21	28.8	1.00	28.8	9
2	1.2	1244	4.5	52	21	28.8	0.97	27.936	6
3	0.8	23940	1.5	52	21	28.8	0.94	27.072	1
4	0.8	2394	4	52	21	28.8	0.90	25.92	2
5	2.9	9576	1.5	52	21	28.8	0.85	24.48	5
6	1.2	2011	3.5	52	21	28.8	0.82	23.616	4
7	0.9	28728	1.5	52	21	28.8	0.80	23.04	0
8	1.8	4788	1.5	52	21	28.8	0.77	22.176	6
9	3.5	2872	4	52	21	28.8	0.72	20.736	6
Total Settlement									39