CALCULATION SHEETS OF

DEEP CEMENT MIXING METHOD

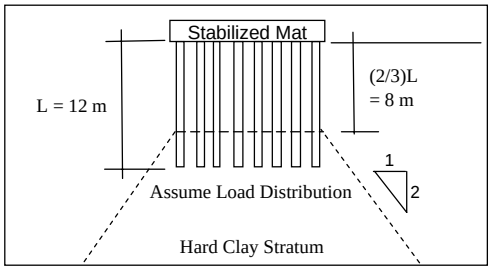
SECTION 1-2 (KM 3+700 ~ 3+821)

1-2a Estimated Settlement for Deep Cement Mixing Method

Section 1-2 km 3+700 to 3+821 (3+820) - Main Road (Dia. 0.8m@2.2m; Column Length = 12 m)

Final Grade, FG =	+3.470	m	Road Height =	**2.28**	m	Road Width =	60	m
Original Ground, OGL =	+1.190	m	DCM Length =	**12**	m	Side Slope =	1:1.5	
Platform Level =	+1.450	m	Tip of DCM =	**-10.55**	m	Treated Width =	59.4	m

Surchage Layer	γ_t (ton/m^3)	Thickness (m)	Surcharge Loading (ton/m^2)
Traffic Load			1.18
Pavement	2.3	0.85	1.96
Subgrade	2.0	0.30	0.60
Fill	1.8	0.33	0.59
Sand-Cement Mat	2.2	0.80	1.76
Total	-	2.28	**6.09**



Column Shortening:

Axial Deformation of Deep Mixing Column Block, $S1 = qH/(aE_{col}+(1-a)E_{soil})$ = **5.3** cm

where q = Surcharge Loading = 6.09 ton/m^2

H = 2 /3 Column Length = 8.00 m

a = Relative Column Area = $A_{col}/(SxS)$ = 0.104

d = Diameter of the deep mixing column 0.8 m

A_{col} = Cross Section Area of Deep Mixing Column = 0.503 m^2

S = Spacing of Column 2.2 m

E_{col} = Modulus of Elasticity of Column Material = $200S_{col}$ = 8000 ton/m^2

S_{col} = Undrained Shear Strength of Column Material = 40 ton/m^2

E_{soil} = Modulus of Elasticity of Surrounding Soil = $100C_u$ = 100 ton/m^2

C_u = Undrained Shear Strength of Surrounding Soil = 1.0 ton/m^2

Consolidation Settlement : Groundwater Level = +0.5 m

Layer	Elevation (m)		Thickness (m)	γ_t (ton/m^3)	σ'_{vo} (ton/m^2)	σ'_p (ton/m^2)	Load Distributed Width (m)	$\Delta\sigma'_v$ (ton/m^2)	σ'_{vf} (ton/m^2)	OCR	CR	RR	ρ_c (cm)
1	+1.19	-2.50	3.7	1.50	1.6								
2	-2.50	-5.00	2.5	1.45	3.1								
3	-5.00	-6.55	1.6	1.45	4.0								
4	-6.55	-7.00	0.5	1.45	4.5	7.1	59.6	6.1	10.5	1.60	0.350	0.044	3.1
5	-7.00	-9.00	2.0	1.45	5.0	6.3	60.9	5.9	11.0	1.25	0.350	0.044	17.8
6	-9.00	-11.00	2.0	1.45	5.9	7.4	62.9	5.8	11.7	1.25	0.350	0.044	14.7
7	-11.00	-13.46	2.5	1.45	6.9	7.6	65.1	5.6	12.5	1.10	0.350	0.044	18.9
8	-13.46	-17.46	4.0	1.8	9.1	13.6	68.3	5.3	14.4	1.50	0.160	0.020	2.9
9	-17.46	-21.00	3.5	2	12.4	31.1	72.1	5.0	17.5	2.50	0.160	0.020	1.0
10	-21.00	-24.90	3.9	2	16.2	40.4	75.8	4.8	20.9	2.50	0.160	0.020	0.9
Total Thickness =			**26.1**	Total Consolidation Settlement, ρ_{ct} =									**59.4**

Total Settlement :

Layer	Soil Type	Fill Height (m)	Applied load (ton/m^2)	Column Shortening, S1 (cm)	Total Consolidation Settlement (cm)	Total Settlement (cm)
1 - 3	DCM	2.28	6.09	5.3	-	***64.7***
4 - 10	Clay	2.28	6.09	-	59.4	

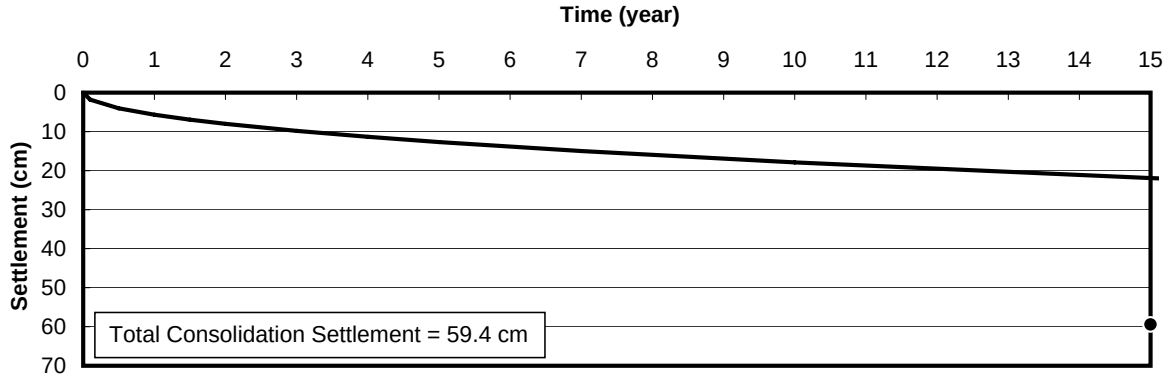
1-2b Rate of Consolidation Settlement for DCM (Dia. 0.8m@2.2m; Column Length = 12 m)
Section 1-2 km 3+700 to 3+821 (3+820) - Main Road

Conversion to Equivalent Thickness of Same Coefficient of Consolidation

Compressible Layer No.	Bottom EL. of Layer (m)	Thickness Layer (m)	Coefficient of Consolidation, c_v (x 10^{-3}) cm^2/s	Equivalent Parameters		
				c_{ve} (x 10^{-3}) cm^2/s	c_{ve} (m^2/year)	Thickness (m)
1	-2.5	3.7	0.25	0.25	0.79	3.7
2	-5.0	2.5	0.25	0.25	0.79	2.5
3	-6.6	1.6	0.25	0.25	0.79	1.6
4	-7.0	0.5	0.25	0.25	0.79	0.5
5	-9.0	2.0	0.25	0.25	0.79	2.0
6	-11.0	2.0	0.25	0.25	0.79	2.0
7	-13.5	2.5	0.25	0.25	0.79	2.5
8	-17.5	4.0	0.80	0.25	0.79	2.2
9	-21.0	3.5	0.80	0.25	0.79	2.0
10	-24.9	3.9	0.80	0.25	0.79	2.2
Total Equivalent Thickness of Compressible Layer =						21.0
Drainage Path:						2
Equivalent Drainage Length =						**10.5**

Calculation of Rate of Settlement

Time (Year)	Road Height (m)	Total Consolidation Settlement (cm)	Time Factor, Tv	Degree of Consolidation, U (%)	Consolidation Settlement (cm)	Column Shortening, S1 (cm)	Total Settlement (cm)
0.0	2.28	59.4	0.0000	0	**0**	5.3	5.3
0.1	2.28	59.4	0.0007	3.0	**1.8**	5.3	7.1
0.5	2.28	59.4	0.0036	6.7	**4.0**	5.3	9.3
1.0	2.28	59.4	0.0071	9.5	**5.7**	5.3	11.0
1.5	2.28	59.4	0.0107	11.7	**6.9**	5.3	12.2
2.0	2.28	59.4	0.0142	13.5	**8.0**	5.3	13.3
3.0	2.28	59.4	0.0214	16.5	**9.8**	5.3	15.1
4.0	2.28	59.4	0.0285	19.0	**11.3**	5.3	16.6
5.0	2.28	59.4	0.0356	21.3	**12.7**	5.3	17.9
7.0	2.28	59.4	0.0498	25.2	**15.0**	5.3	20.3
10.0	2.28	59.4	0.0712	30.1	**17.9**	5.3	23.2
15.0	2.28	59.4	0.1068	36.9	**21.9**	5.3	27.2
20.0	2.28	59.4	0.1424	42.6	**25.3**	5.3	30.6

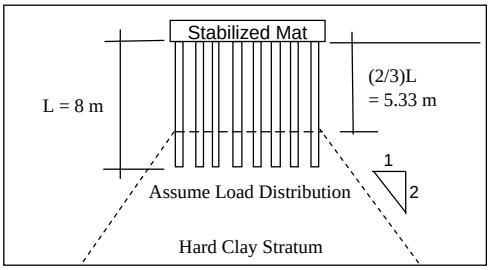


1-2c Estimated Settlement for Deep Cement Mixing Method

Section 1-2 km 3+700 to 3+821 (3+820) - Sidewalk (Dia. 0.8m@2.2m; Column Length = 8 m)

Final Grade, FG =	+3.470	m	Road Height =	**2.28**	m	Road Width =	60	m
Original Ground, OGL =	+1.190	m	DCM Length =	**8**	m	Base Width =	1:1.5	
Platform Level =	+1.450	m	Tip of DCM =	**-6.55**	m	Treated Width =	59.4	m

Surchage Layer	γ_t (ton/m^3)	Thickness (m)	Surcharge Loading (ton/m^2)
Traffic Load			
Pavement			
Subgrade			
Fill	1.8	2.28	4.10
Shallow Mixing			
Total	-	2.28	**4.10**



Column Shortening:

Axial Deformation of Deep Mixing Column Block, $S1 = qH/(aE_{col}+(1-a)E_{soil})$ = **2.4** cm

where q = Surcharge Loading = 4.10 ton/m^2

H = 2 /3 Column Length = 5.33 m

a = Relative Column Area = $A_{col}/(SxS)$ = 0.104

d = Diameter of the deep mixing column 0.8 m

A_{col} = Cross Section Area of Deep Mixing Column = 0.503 m^2

S = Spacing of Column 2.2 m

E_{col} = Modulus of Elasticity of Column Material = $200S_{col}$ = 8000 ton/m^2

S_{col} = Undrained Shear Strength of Column Material = 40 ton/m^2

E_{soil} = Modulus of Elasticity of Surrounding Soil = $100C_u$ = 100 ton/m^2

C_u = Undrained Shear Strength of Surrounding Soil = 1.0 ton/m^2

Consolidation Settlement : Groundwater Level = +0.5 m

Layer	Elevation (m)		Thickness (m)	γ_t (ton/m^3)	σ'_{vo} (ton/m^2)	σ'_p (ton/m^2)	Load Distributed Width (m)	$\Delta\sigma'_v$ (ton/m^2)	σ'_{vf} (ton/m^2)	OCR	CR	RR	ρ_c (cm)
1	+1.19	-2.50	3.7	1.5	1.6								
2	-2.50	-3.88	1.4	1.45	2.8								
3	-3.88	-5.00	1.1	1.45	3.4	5.5	60.0	4.1	7.5	1.60	0.350	0.044	6.3
4	-5.00	-7.00	2.0	1.45	4.1	6.6	61.5	4.0	8.1	1.60	0.350	0.044	8.0
5	-7.00	-9.00	2.0	1.45	5.0	6.3	63.5	3.8	8.8	1.25	0.350	0.044	11.4
6	-9.00	-11.00	2.0	1.45	5.9	7.4	65.5	3.7	9.6	1.25	0.350	0.044	8.9
7	-11.00	-13.46	2.5	1.45	6.9	7.6	67.7	3.6	10.5	1.10	0.350	0.044	12.6
8	-13.46	-17.46	4.0	1.8	9.1	13.6	71.0	3.4	12.5	1.50	0.160	0.020	1.1
9	-17.46	-21.00	3.5	2	12.4	31.1	74.7	3.3	15.7	2.50	0.160	0.020	0.7
10	-21.00	-24.90	3.9	2	16.2	40.4	78.5	3.1	19.3	2.50	0.160	0.020	0.6
Total Thickness =			**26.1**	Total Consolidation Settlement, ρ_{ct} =									**49.6**

Total Settlement :

Layer	Soil Type	Fill Height (m)	Applied load (ton/m^2)	Column Shortening, S1 (cm)	Total Consolidation Settlement (cm)	Total Settlement (cm)
1 - 2	DCM	2.28	4.10	2.4	-	***52.0***
3 - 10	Clay	2.28	4.10	-	49.6	

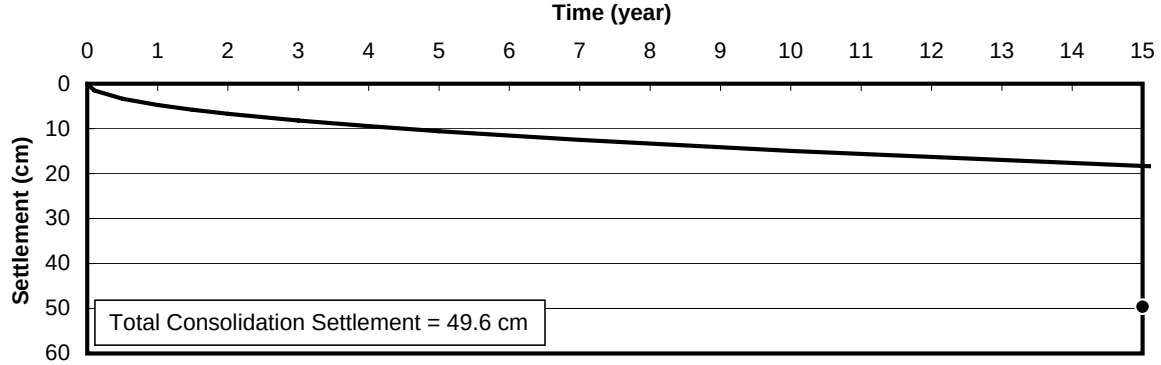
1-2d Rate of Consolidation Settlement for DCM (Dia. 0.8m@2.2m; Column Length = 8 m)
Section 1-2 km 3+700 to 3+821 (3+820) - Sidewalk

Conversion to Equivalent Thickness of Same Coefficient of Consolidation

Compressible Layer No.	Bottom EL. of Layer (m)	Thickness Layer (m)	Coefficient of Consolidation, c_v (x 10^{-3}) cm^2/s	Equivalent Parameters		
				c_{ve} (x 10^{-3}) cm^2/s	c_{ve} (m^2/year)	Thickness (m)
1	-2.5	3.7	0.25	0.25	0.79	3.7
2	-3.9	1.4	0.25	0.25	0.79	1.4
3	-5.0	1.1	0.25	0.25	0.79	1.1
4	-7.0	2.0	0.25	0.25	0.79	2.0
5	-9.0	2.0	0.25	0.25	0.79	2.0
6	-11.0	2.0	0.25	0.25	0.79	2.0
7	-13.5	2.5	0.25	0.25	0.79	2.5
8	-17.5	4.0	0.80	0.25	0.79	2.2
9	-21.0	3.5	0.80	0.25	0.79	2.0
10	-24.9	3.9	0.80	0.25	0.79	2.2
Total Equivalent Thickness of Compressible Layer =						21.0
Drainage Path:						2
Equivalent Drainage Length =						**10.5**

Calculation of Rate of Settlement

Time (Year)	Road Height (m)	Total Consolidation Settlement (cm)	Time Factor, Tv	Degree of Consolidation, U (%)	Consolidation Settlement (cm)	Column Shortening, S1 (cm)	Total Settlement (cm)
0.0	2.28	49.6	0.0000	0	**0**	2.4	2.4
0.1	2.28	49.6	0.0007	3.0	**1.5**	2.4	3.9
0.5	2.28	49.6	0.0036	6.7	**3.3**	2.4	5.7
1.0	2.28	49.6	0.0071	9.5	**4.7**	2.4	7.1
1.5	2.28	49.6	0.0107	11.7	**5.8**	2.4	8.2
2.0	2.28	49.6	0.0142	13.5	**6.7**	2.4	9.1
3.0	2.28	49.6	0.0214	16.5	**8.2**	2.4	10.6
4.0	2.28	49.6	0.0285	19.0	**9.4**	2.4	11.8
5.0	2.28	49.6	0.0356	21.3	**10.6**	2.4	12.9
7.0	2.28	49.6	0.0498	25.2	**12.5**	2.4	14.9
10.0	2.28	49.6	0.0712	30.1	**14.9**	2.4	17.3
15.0	2.28	49.6	0.1068	36.9	**18.3**	2.4	20.7
20.0	2.28	49.6	0.1424	42.6	**21.1**	2.4	23.5



1-2e Summary of Stability Analysis for Different Modes of Failures

Section 1-2 km 3+700 to 3+821 (3+820) - Main Road

Mode of Failure		Deep Mixing Method d = 0.8 m, ss = sl = 2.2 m	
		FS	Remarks
DCM	Material Capacity of Deep Cement Mixing Column	1.48	FS = $(q_u x A_{col})/(qxssxsl)$
	Column Capacity of Deep Cement Mixing Column	1.56	FS = $Q_{ult}/(\sigma x A_{col})$
Sand Cement Stabilized Mat	Flexure of Sand Cement Stabilized Layer	1.91	FS = f_t/σ_t
	Punching Shear of Sand Cement Stabilized Layer	2.45	FS = ν_c/τ

Notes :

1. $M = [0.65q(sl-d)^2] / 8$
2. $\sigma_t = (Mt/2) / (t^3/12)$
3. $f_r = 6.23\sqrt{f_c'}$
4. $f_t = 0.21\ f_r$
5. $\tau = q[s^2 - \pi(d+t)^2/4] / [\pi t(d+t)]$
6. $\nu_c = 0.79\ \sqrt{f_c'}$
7. $Q_{ult} = \pi d(\sum c_{u,i}L_i) + 9c_u(\pi d^2/4)$
8. $\sigma = q / [\rho+(1-\rho)(E_{soil}/E_{col})]$

q_u : unconfined compressive strength of deep cement mixing column = 80 ton/sq.m

q : unit load due to traffic load, weight of pavement, backfill and sand cement stabilized layers down to bottom of mat; in this analysis, q = Design Load = 5.62 ton/sq.m

ss and sl: spacings (c/c) between adjacent deep cement mixing columns (m), and s = (ss+sl)/2 = 2.2 m

d : diameter of deep cement mixing column = 0.8 m

t : thickness of sand cement stabilized layer = 0.8 m

f_c' : compressive strength of sand cement stabilized mat, fc' = 150 ton/sq.m

f_r : modulus of rupture, (ton/m^2)

E_{soil}, E_{col} : moduli of soil and deep cement mixing column (ton/m^2), assume Esoil = $100c_u$ and Ecol = $200(0.5q_u)$

L_i : thickness of the clay layer (m)

M : maximum induced bending moment (ton.m/m)

ν_c : allowable shear stress, (ton/m^2)

τ : shear stress on the most critical surface (ton/m^2)

c_u : undrained shear strength of the clay at the column tip (ton/m^2)

$c_{u,i}$: undrained shear strength of the surrounding clay (ton/m^2)

ρ : ratio of the total area of deep cement mixing columns to the stabilized area, $=A_{col}/(ssxsl)$

Q_{ult}: bearing capacity of deep cement mixing column (ton)

1-2f Estimated Column Capacity for Dia. 0.8 m, L = 12 m

Section 1-2 km 3+700 to 3+821 (3+820) - Main Road

Skin Friction

Elevation (m)		Column Length (m)	Soil Type	Undrained Shear Strength, cu (ton/m^2)	SPT N Value	Unit Skin Friction (ton/m^2)	Skin Friction (ton)	Remarks
from	to							
+1.19	-2.50	3.7	C	1.00	-	0.89	8.3	
-2.50	-5.00	2.5	C	1.00	-	0.89	5.6	
-5.00	-6.55	1.6	C	1.30	-	1.14	4.4	
-6.55	-7.00	0.5	C	1.30	-	1.14	1.3	
-7.00	-9.00	2.0	C	1.30	-	1.14	5.7	
-9.00	-11.00	1.6	C	1.65	-	1.42	5.5	
-11.00	-13.46	-	C	1.65	-	-	-	
-13.46	-17.46	-	C	-	6	-	-	
-17.46	-21.00	-	C	-	29	-	-	$f_s = \alpha Su$ or $k \sigma'v \tan \delta$
Column Length		**11.7**				Total Skin Friction (ton)	**30.8**	

Ground Level = +1.19 m
Top of DCM = +1.45 m
Tip of DCM = -10.55 m

Column Length = 12 m
Column Size = 0.8 m
Groundwater Level = +0.5 m

End Bearing

Unit End Bearing	=	14.9	ton/m^2	(q_e = 9c or qNq)
Area	=	0.50	m^2	
End Bearing Capacity	=	**7.5**	ton	

Ultimate Pile Capacity

Ultimate Pile Capacity	=	**38.3**	ton