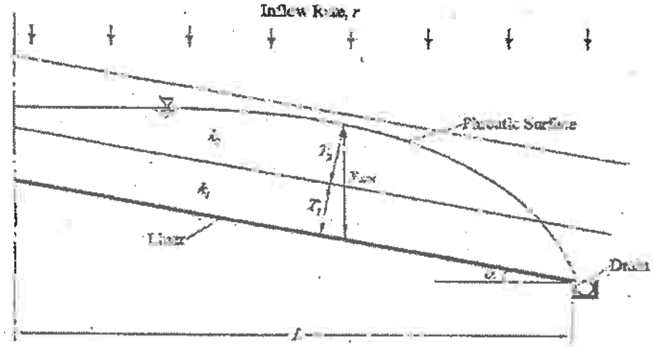
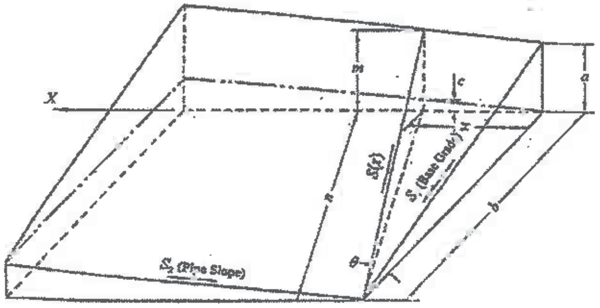
APPENDIX B

Mound Model Leachate Head Calculations

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-F Phase 2 South Area

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	3.4%	
S_2 =	0.034	

S (tanα)	0.0394	
α =	0.0394	radians
α =	2.259	degrees
sinα	0.0394	
cosα	0.9992	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.24	mm

Assumed

y_{max}	31.02	cm
y_{max}	310.24	mm

compare

input
trial & error
output

Trial 1

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	3.4%	
S_2 =	0.034	

S (tanα)	0.0394	
α =	0.0394	radians
α =	2.259	degrees
sinα	0.0394	
cosα	0.9992	

r	5.79	mm/day
r	0.579	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.19	cm/day

b	4347.20	cm
L	8574.02	cm

Giroud's 92 Method

A	0.294523
B	-0.281835
j	0.909472

Calculated

y_{max}	25.16	cm
y_{max}	251.58	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	3.4%	
S_2 =	0.034	

S (tanα)	0.0394	
α =	0.0394	radians
α =	2.259	degrees
sinα	0.0394	
cosα	0.9992	

$k1$	12.2	mm/sec
$k2$	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	116	mm

k_{eq}	1.078	mm/sec

Assumed

y_{max}	121.28	mm

Assumed

y_{max}	12.13	cm
y_{max}	121.28	mm

compare

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	3.4%	
S_2 =	0.034	

S (tanα)	0.0394	
α =	0.0394	radians
α =	2.259	degrees
sinα	0.0394	
cosα	0.9992	

r	5.79	mm/day
r	0.579	cm/day

k_{eq}	0.1078	cm/sec
k_{eq}	9312.634	cm/day

b	4347.203	cm
L	8574.02	cm

Giroud's 92 Method

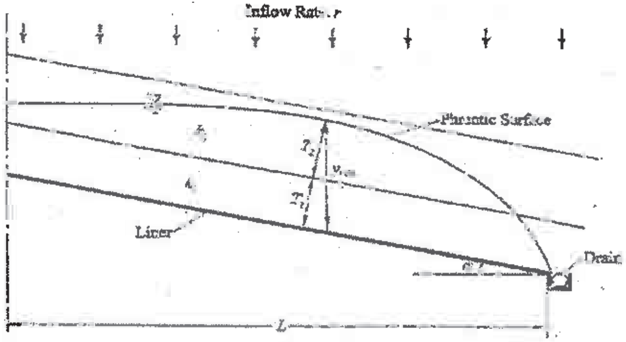
A	0.179297
B	-0.557154
j	0.93126

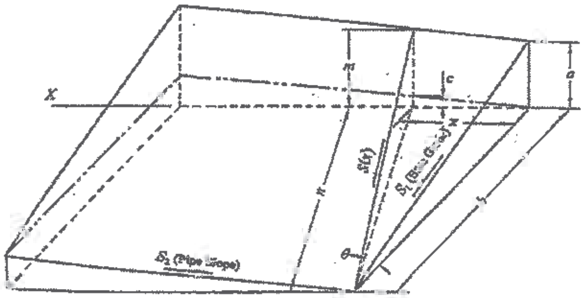
Calculated

y_{max}	12.13	cm
y_{max}	121.28	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-F Phase 2 South Area 2

Base Grade	10.9%	
S_1 =	0.109	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.1090	
α =	0.1086	radians
α =	6.221	degrees
sinα	0.1084	
cosα	0.9941	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	311.84	mm

Assumed

y_{max}	31.18	cm
y_{max}	311.84	mm

compare

input
trial & error
output

Trial 1

Base Grade	10.9%	
S_1 =	0.109	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.1090	
α =	0.1086	radians
α =	6.221	degrees
sinα	0.1084	
cosα	0.9941	

r	8.75	mm/day
r	0.875	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	2502.41	cm
L	2502.41	cm

Giroud's 92 Method

A	0.1070096
B	-0.94202
j	0.9532193

Calculated

y_{max}	4.50	cm
y_{max}	44.99	mm

Trial 2

Base Grade	10.9%	
S_1 =	0.109	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.1090	
α =	0.1086	radians
α =	6.221	degrees
sinα	0.1084	
cosα	0.9941	

$k1$	12.2	mm/sec
$k2$	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	0	mm

k_{eq}	12.200	mm/sec

Assumed

y_{max}	5.03	mm

Assumed

y_{max}	0.50	cm
y_{max}	5.03	mm

compare

Base Grade	10.9%	
S_1 =	0.109	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.1090	
α =	0.1086	radians
α =	6.221	degrees
sinα	0.1084	
cosα	0.9941	

r	8.75	mm/day
r	0.875	cm/day

k_{eq}	1.2200	cm/sec
k_{eq}	105408	cm/day

b	2502.41	cm
L	2502.41	cm

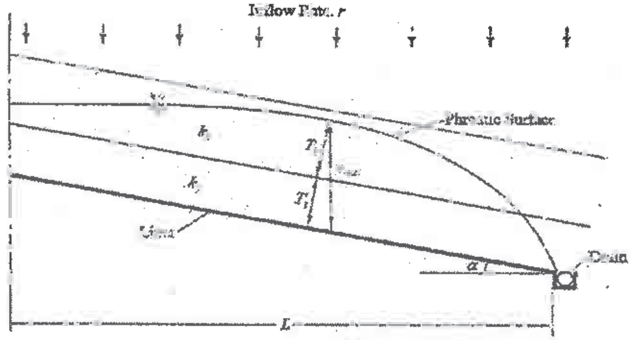
Giroud's 92 Method

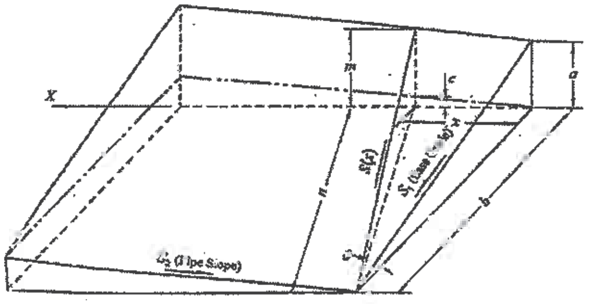
A	0.0142972
B	-3.403096
j	0.9960076

Calculated

y_{max}	0.19	cm
y_{max}	1.91	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media *Developed by Xuede (Dan) Qian* **2008**





MC VI-F Phase 2 NE Area

Base Grade	7.4%	
S₁ =	0.074	

input
trial & error
output

Pipe Slope	0.0%	
S₂ =	0.000	

S (tanα)	0.0740	
α =	0.0739	radians
α =	4.232	degrees
sinα	0.0738	
cosα	0.9973	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.85	mm

Assumed

y_{max}	31.08	cm
y_{max}	310.85	mm

compare

Trial 1

Base Grade	7.4%	
S₁ =	0.074	

Pipe Slope	0.0%	
S₂ =	0.000	

S (tanα)	0.0740	
α =	0.0739	radians
α =	4.232	degrees
sinα	0.0738	
cosα	0.9973	

r	9.41	mm/day
r	0.941	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	7552.94	cm
L	7552.94	cm

Giroud's 92 Method

A	0.1817208
B	0.548481
j	[illegible]

Calculated

y_{max}	20.49	cm
y_{max}	204.89	mm

Trial 2

Base Grade	7.4%	
S₁ =	0.074	

Pipe Slope	0.0%	
S₂ =	0.000	

S (tanα)	0.0740	
α =	0.0739	radians
α =	4.232	degrees
sinα	0.0738	
cosα	0.9973	

$k1$	12.2	mm/sec
$k2$	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	16	mm

k_{eq}	5.158	mm/sec

Assumed

y_{max}	21.15	mm

Assumed

y_{max}	2.11	cm
y_{max}	21.15	mm

compare

Base Grade	7.4%	
S₁ =	0.074	

Pipe Slope	0.0%	
S₂ =	0.000	

S (tanα)	0.0740	
α =	0.0739	radians
α =	4.232	degrees
sinα	0.0738	
cosα	0.9973	

r	9.41	mm/day
r	0.941	cm/day

k_{eq}	0.5158	cm/sec
k_{eq}	44560.814	cm/day

b	7552.944	cm
L	7552.94	cm

Giroud's 92 Method

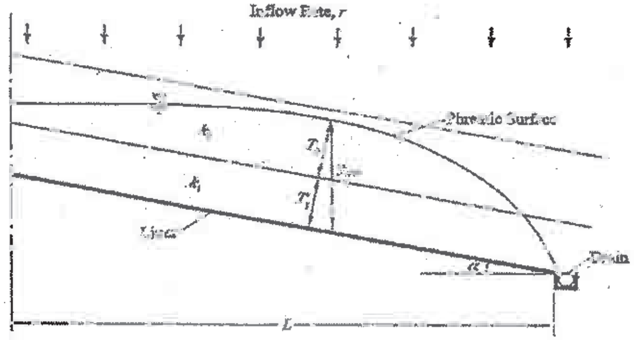
A	0.0415847
B	-1.907346
j	0.9821831

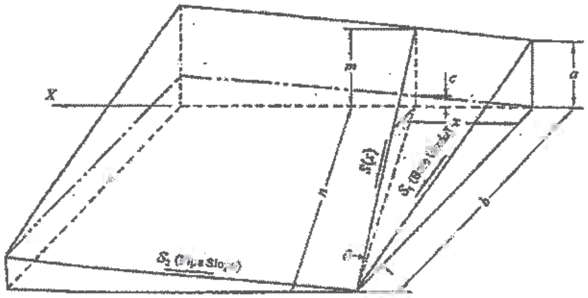
Calculated

y_{max}	2.11	cm
y_{max}	21.15	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-F Phase 2 North Area

Base Grade	7.9%	
S₁ =	0.079	

input
trial & error
output

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0790	
α =	0.0788	radians
α =	4.517	degrees
sinα	0.0788	
cosα	0.9969	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.97	mm

Assumed

y_{max}	31.10	cm
y_{max}	310.97	mm

compare

Trial 1

Base Grade	7.9%	
S_1 =	0.079	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0790	
α =	0.0788	radians
α =	4.517	degrees
sinα	0.0788	
cosα	0.9969	

r	9.14	mm/day
r	0.914	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	9381.74	cm
L	9381.74	cm

Giroud's 92 Method

A	0.1544403
B	-0.614643
j	0.9350999

Calculated

y_{max}	23.40	cm
y_{max}	234.01	mm

Trial 2

Base Grade	7.9%	
S_1 =	0.079	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0790	
α =	0.0788	radians
α =	4.517	degrees
sinα	0.0788	
cosα	0.9969	

$k1$	12.2	mm/sec
$k2$	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	50	mm

k_{eq}	2.190	mm/sec

Assumed

y_{max}	55.46	mm

Assumed

y_{max}	5.55	cm
y_{max}	55.46	mm

compare

Base Grade	7.9%	
S_1 =	0.079	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0790	
α =	0.0788	radians
α =	4.517	degrees
sinα	0.0788	
cosα	0.9969	

r	9.14	mm/day
r	0.914	cm/day

k_{eq}	0.2190	cm/sec
k_{eq}	18918.375	cm/day

b	9381.74	cm
L	9381.74	cm

Giroud's 92 Method

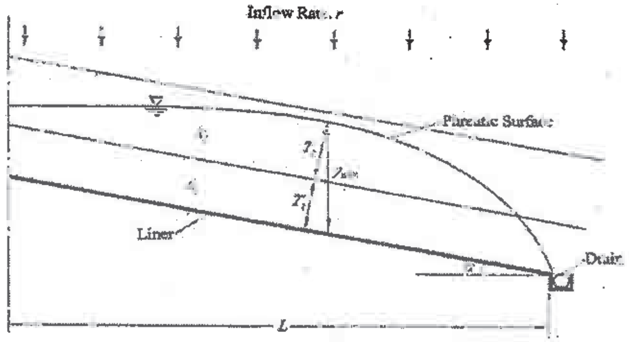
A	0.0642806
B	-1.420673
j	0.9710138

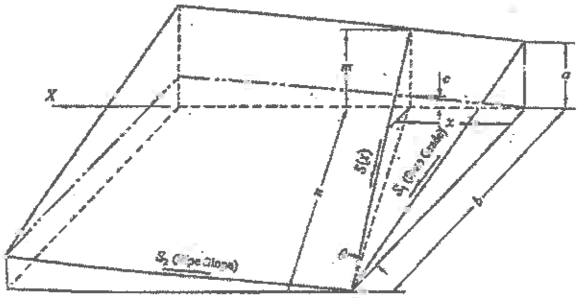
Calculated

y_{max}	5.55	cm
y_{max}	55.46	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-F Phase 2 North Area 2

Base Grade	5.6%	
S_1 =	0.056	

input
trial & error
output

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0560	
α =	0.0559	radians
α =	3.205	degrees
sinα	0.0559	
cosα	0.9984	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.49	mm

Assumed

y_{max}	31.05	cm
y_{max}	310.49	mm

compare

Trial 1

Base Grade	5.6%	
S_1 =	0.056	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0560	
α =	0.0559	radians
α =	3.205	degrees
sinα	0.0559	
cosα	0.9984	

r	9.62	mm/day
r	0.962	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.19	cm/day

b	5108.45	cm
L	5108.45	cm

Giroud's 92 **Method**

A	0.261036
B	-0.340239
j	0.914808

Calculated

y_{max}	17.88	cm
y_{max}	178.78	mm

Trial 2

Base Grade	5.6%	
S_1 =	0.056	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0560	
α =	0.0559	radians
α =	3.205	degrees
sinα	0.0559	
cosα	0.9984	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	8	mm

k_{eq}	7.618	mm/sec

Assumed

y_{max}	13.02	mm

Assumed

y_{max}	1.30	cm
y_{max}	13.02	mm

compare

Base Grade	5.6%	
S_1 =	0.056	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0560	
α =	0.0559	radians
α =	3.205	degrees
sinα	0.0559	
cosα	0.9984	

r	9.62	mm/day
r	0.962	cm/day

k_{eq}	0.7618	cm/sec
k_{eq}	65819.67	cm/day

b	5108.45	cm
L	5108.45	cm

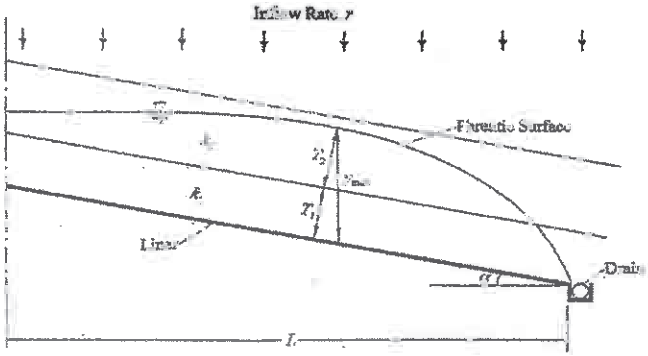
Giroud's 92 Method

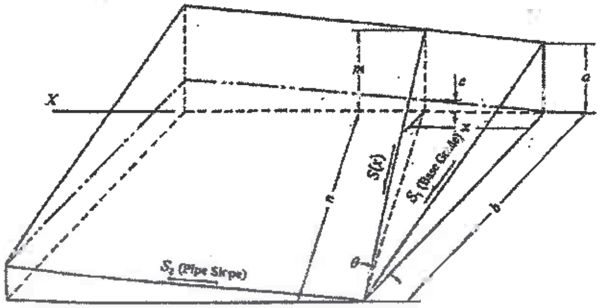
A	0.046811
B	-1.767984
j	0.979518

Calculated

y_{max}	1.30	cm
y_{max}	13.02	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media *Developed by Xuede (Dan) Qian* 2008





MC VI-F Phase 1 South Area

Base Grade	2.0%	
S_1 =	0.020	

input
trial & error
output

Pipe Slope	7.7%	
S_2 =	0.077	

S (tanα)	0.0796	
α =	0.0794	radians
α =	4.549	degrees
sinα	0.0793	
cosα	0.9969	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.98	mm

Assumed

y_{max}	31.10	cm
y_{max}	310.98	mm

compare

Trial 1

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	7.7%	
S_2 =	0.077	

S (tanα)	0.0796	
α =	0.0794	radians
α =	4.549	degrees
sinα	0.0793	
cosα	0.9969	

r	6.89	mm/day
r	0.689	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.19	cm/day

b	3614.46	cm
L	14377.42	cm

Giroud's 92 Method

A	0.136617
B	-0.747354
j	0.943166

Calculated

y_{max}	27.30	cm
y_{max}	273.01	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	7.7%	
S_2 =	0.077	

S (tanα)	0.0796	
α =	0.0794	radians
α =	4.549	degrees
sinα	0.0793	
cosα	0.9969	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	161	mm

k_{eq}	0.818	mm/sec

Assumed

y_{max}	166.41	mm

Assumed

y_{max}	16.64	cm
y_{max}	166.41	mm

compare

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	7.7%	
S_2 =	0.077	

S (tanα)	0.0796	
α =	0.0794	radians
α =	4.549	degrees
sinα	0.0793	
cosα	0.9969	

r	6.89	mm/day
r	0.689	cm/day

k_{eq}	0.0818	cm/sec
k_{eq}	7071.355	cm/day

b	3614.459	cm
L	14377.42	cm

Giroud's 92 Method

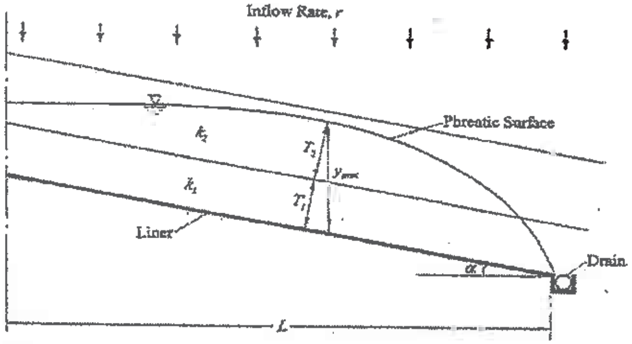
A	0.098784
B	-1.010851
j	0.956322

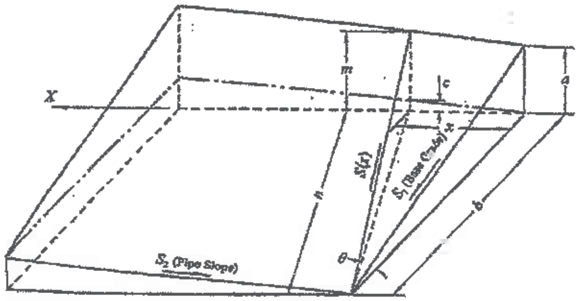
Calculated

y_{max}	16.64	cm
y_{max}	166.41	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-F Phase 1 South Area 2

Base Grade	4.0%	
S₁ =	0.040	

Pipe Slope	7.7%	
S₂ =	0.077	

S (tanα)	0.0868	
α =	0.0866	radians
α =	4.959	degrees
sinα	0.0864	
cosα	0.9963	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T₁	5	mm
(T₂)assumed	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	311.16	mm

Assumed

y_{max}	31.12	cm
y_{max}	311.16	mm

input
trial & error
output

compare

Trial 1

Base Grade	4.0%	
S₁ =	0.040	

Pipe Slope	7.7%	
S₂ =	0.077	

S (tanα)	0.0868	
α =	0.0866	radians
α =	4.959	degrees
sinα	0.0864	
cosα	0.9963	

r	9.35	mm/day
r	0.935	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4208.19	cm/day

b	4334.72	cm
L	9403.08	cm

Giroud's 92 Method

A	0.148336
B	-0.48883
j	0.93962

Calculated

y_{max}	22.07	cm
y_{max}	220.71	mm

Trial 2

Base Grade	4.0%	
S₁ =	0.040	

Pipe Slope	7.7%	
S₂ =	0.077	

S (tanα)	0.0868	
α =	0.0866	radians
α =	4.959	degrees
sinα	0.0864	
cosα	0.9963	

$k1$	12.2	mm/sec
$k2$	0.1	mm/sec

T₁	5	mm
(T₂)assumed	27	mm

k_{eq}	3.604	mm/sec

Assumed

y_{max}	31.94	mm

Assumed

y_{max}	3.19	cm
y_{max}	31.94	mm

compare

Base Grade	4.0%	
S₁ =	0.040	

Pipe Slope	7.7%	
S₂ =	0.077	

S (tanα)	0.0868	
α =	0.0866	radians
α =	4.959	degrees
sinα	0.0864	
cosα	0.9963	

r	9.35	mm/day
r	0.935	cm/day

k_{eq}	0.3604	cm/sec
k_{eq}	31138	cm/day

b	4334.724	cm
L	9403.08	cm

Giroud's 92 Method

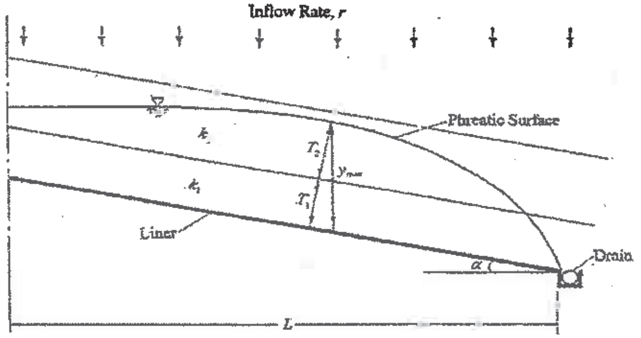
A	0.042466
B	-1.28221
j	0.98173

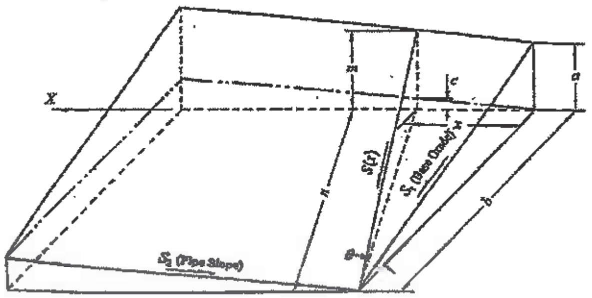
Calculated

y_{max}	3.19	cm
y_{max}	31.92	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-F Phase 1 North Area

Base Grade	9.6%	
S_1 =	0.096	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0960	
α =	0.0957	radians
α =	5.484	degrees
sinα	0.0956	
cosα	0.9954	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	311.43	mm

input
trial & error
[illegible]

Assumed

y_{max}	31.14	cm
y_{max}	311.43	mm

compare

Trial 1

Base Grade	9.6%	
S_1 =	0.096	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0960	
α =	0.0957	radians
α =	5.484	degrees
sinα	0.0956	
cosα	0.9954	

r	9.43	mm/day
r	0.943	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	9665.21	cm
L	9665.21	cm

Giroud's 92 Method

A	0.1314261
B	-0.776722
j	0.9448107

Calculated

y_{max}	20.91	cm
y_{max}	209.12	mm

Trial 2

Base Grade	9.6%	
S_1 =	0.096	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0960	
α =	0.0957	radians
α =	5.484	degrees
sinα	0.0956	
cosα	0.9954	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	16	mm

k_{eq}	5.264	mm/sec

Assumed

y_{max}	20.68	mm

Assumed

y_{max}	2.07	cm
y_{max}	20.68	mm

compare

Base Grade	9.6%	
S_1 =	0.096	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0960	
α =	0.0957	radians
α =	5.484	degrees
sinα	0.0956	
cosα	0.9954	

r	9.43	mm/day
r	0.943	cm/day

k_{eq}	0.5264	cm/sec
k_{eq}	45481.388	cm/day

b	9665.21	cm
L	9665.21	cm

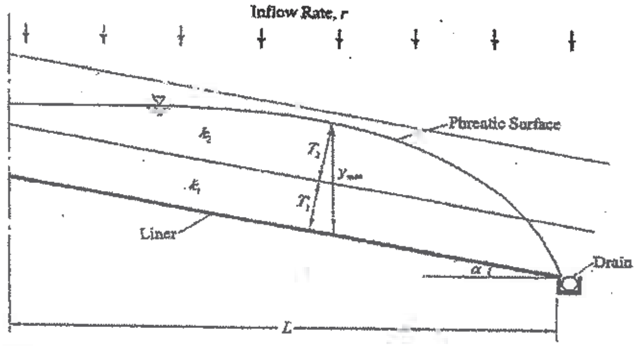
Giroud's 92 Method

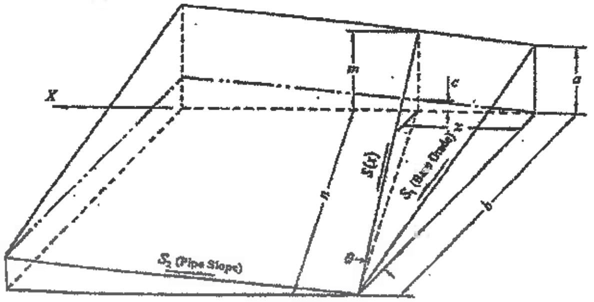
A	0.029692
B	-2.312832
j	0.9983575

Calculated

y_{max}	2.07	cm
y_{max}	20.65	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media *Developed by Xuede (Dan) Qian* **2008**





MC VI-F Phase 1 North Area 2

Base Grade	7.7%	
S_1 =	0.077	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0770	
α =	0.0768	radians
α =	4.403	degrees
sinα	0.0768	
cosα	0.9970	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.92	mm

Assumed

y_{max}	31.09	cm
y_{max}	310.92	mm

compare

input
trial & error
output

Trial 1

Base Grade	7.7%	
S_1 =	0.077	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0770	
α =	0.0768	radians
α =	4.403	degrees
sinα	0.0768	
cosα	0.9970	

r	9.93	mm/day
r	0.993	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	[illegible]	cm/day

b	5824.73	cm
L	5824.73	cm

Giroud's 92 Method

A	[illegible]
B	0.56886
j	[illegible]

Calculated

y_{max}	16.06	cm
y_{max}	160.55	mm

Trial 2

Base Grade	7.7%	
S_1 =	0.077	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0770	
α =	0.0768	radians
α =	4.403	degrees
sinα	0.0768	
cosα	0.9970	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	3	mm

k_{eq}	10.206	mm/sec

Assumed

y_{max}	8.44	mm

Assumed

y_{max}	0.84	cm
y_{max}	8.44	mm

compare

Base Grade	7.7%	
S_1 =	0.077	

Pipe Slope	0.0%	
S_2 =	0.000	

S (tanα)	0.0770	
α =	0.0768	radians
α =	4.403	degrees
sinα	0.0768	
cosα	0.9970	

r	9.93	mm/day
r	0.993	cm/day

k_{eq}	1.0206	cm/sec
k_{eq}	[illegible]	cm/day

b	5824.73	cm
L	5824.73	cm

Giroud's 92 Method

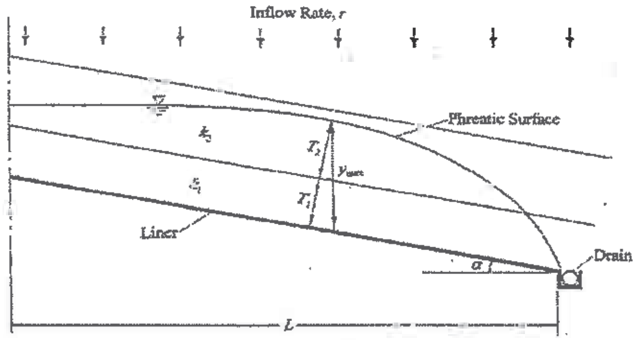
A	0.0267111
B	-2.4753
j	0.9899635

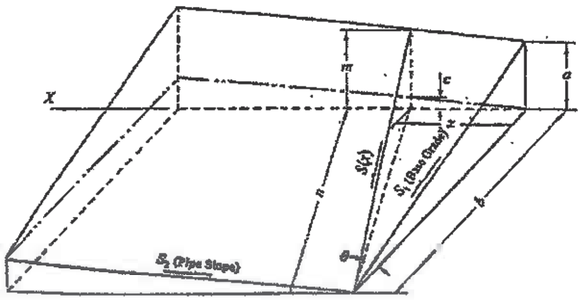
Calculated

y_{max}	0.84	cm
y_{max}	8.44	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-G Phase 1 East Area

Base Grade	2.0%	
S_1 =	0.020	

input
trial & error
output

Pipe Slope	1.5%	
S_2 =	0.015	

S (tanα)	0.0250	
α =	0.0250	radians
α =	1.432	degrees
sinα	0.0250	
cosα	0.9997	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.10	mm

Assumed

y_{max}	31.01	cm
y_{max}	310.10	mm

compare

Trial 1

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	1.5%	
S_2 =	0.015	

S (tanα)	0.0250	
α =	0.0250	radians
α =	1.432	degrees
sinα	0.0250	
cosα	0.9997	

r	5.28	mm/day
r	0.528	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.19	cm/day

b	4888.99	cm
L	6111.24	cm

Giroud's 92 Method

A	0.491066
B	0.035066
j	0.890682

Calculated

y_{max}	23.33	cm
y_{max}	233.39	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	1.5%	
S_2 =	0.015	

S (tanα)	0.0250	
α =	0.0250	radians
α =	1.432	degrees
sinα	0.0250	
cosα	0.9997	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	92	mm

k_{eq}	1.311	mm/sec

Assumed

y_{max}	97.42	mm

Assumed

y_{max}	9.74	cm
y_{max}	97.42	mm

compare

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	1.5%	
S_2 =	0.015	

S (tanα)	0.0250	
α =	0.0250	radians
α =	1.432	degrees
sinα	0.0250	
cosα	0.9997	

r	5.28	mm/day
r	0.528	cm/day

k_{eq}	0.1311	cm/sec
k_{eq}	11322.93	cm/day

b	4888.992	cm
L	6111.24	cm

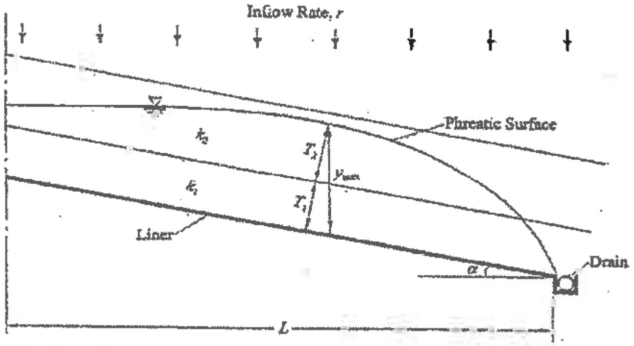
Giroud's 92 Method

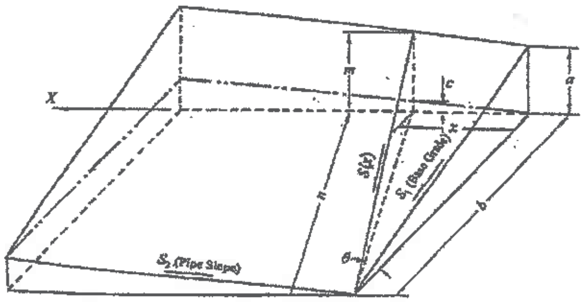
A	0.264894
B	-0.332846
j	0.913974

Calculated

y_{max}	9.74	cm
y_{max}	97.42	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media *Developed by Xuede (Dan) Qian* **2008**





MC VI-G Phase 1 West Area

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	3.3%	
S_2 =	0.033	

S (tanα)	0.0386	
α =	0.0386	radians
α =	2.210	degrees
sinα	0.0386	
cosα	0.9993	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.23	mm

Assumed

y_{max}	31.02	cm
y_{max}	310.23	mm

compare

input
trial & error
output

Trial 1

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	3.3%	
S_2 =	0.033	

S (tanα)	0.0386	
α =	0.0386	radians
α =	2.210	degrees
sinα	0.0386	
cosα	0.9993	

r	8.02	mm/day
r	0.802	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	[illegible]	cm/day

b	3097.96	cm
L	5977.13	cm

Giroud's 92 Method

A	0.371108
B	0.18653
j	0.9003

Calculated

y_{max}	23.86	cm
y_{max}	238.59	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	3.3%	
S_2 =	0.033	

S (tanα)	0.0386	
α =	0.0386	radians
α =	2.210	degrees
sinα	0.0386	
cosα	0.9993	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	91	mm

k_{eq}	1.324	mm/sec

Assumed

y_{max}	96.40	mm

Assumed

y_{max}	9.64	cm
y_{max}	96.40	mm

compare

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	3.3%	
S_2 =	0.033	

S (tanα)	0.0386	
α =	0.0386	radians
α =	2.210	degrees
sinα	0.0386	
cosα	0.9993	

r	8.02	mm/day
r	0.802	cm/day

k_{eq}	0.1324	cm/sec
k_{eq}	11435.26	cm/day

b	3097.956	cm
L	5977.13	cm

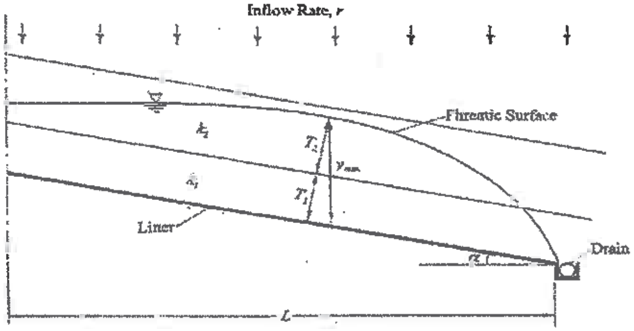
Giroud's 92 Method

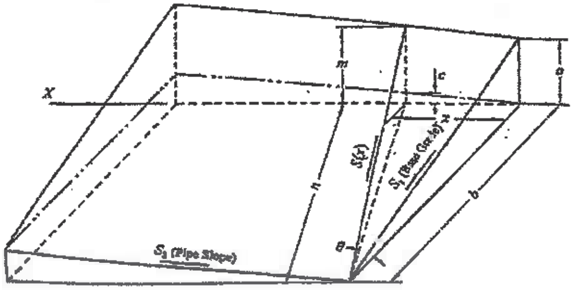
A	0.198711
B	4.492484
j	0.926056

Calculated

y_{max}	9.64	cm
y_{max}	96.40	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media *Developed by Xuede (Dan) Qian* **2008**





MC VI-G Phase 2 West Area

Base Grade	2.0%	
S_1 =	0.020	
Pipe Slope	7.6%	
S_2 =	0.076	
S (tanα)	0.0786	
α =	0.0784	radians
α =	4.493	degrees
sinα	0.0783	
cosα	0.9969	
k_1	12.2	mm/sec
k_2	0.1	mm/sec
T_1	5	mm
$(T_2)_{assumed}$	305	mm
k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.96	mm

Assumed

y_{max}	31.10	cm
y_{max}	310.96	mm

input
trial & error
[illegible]

compare

Trial 1

Base Grade	2.0%	
S_1 =	0.020	
Pipe Slope	7.6%	
S_2 =	0.076	
S (tanα)	0.0786	
α =	0.0784	radians
α =	4.493	degrees
sinα	0.0783	
cosα	0.9969	
r	8.29	mm/day
r	0.829	cm/day
k_{eq}	0.0487	cm/sec
k_{eq}	[illegible]	cm/day
b	2897.22	cm
L	11384.28	cm

Giroud's 92 Method

A	0.1567239
B	-0.65229
j	0.0574978

Calculated

y_{max}	26.02	cm
y_{max}	260.25	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	
Pipe Slope	7.6%	
S_2 =	0.076	
S (tanα)	0.0786	
α =	0.0784	radians
α =	4.493	degrees
sinα	0.0783	
cosα	0.9969	
k1	12.2	mm/sec
k2	0.1	mm/sec
T_1	5	mm
$(T_2)_{assumed}$	120	mm
k_{eq}	1.046	mm/sec

Assumed

y_{max}	125.73	mm

Assumed

y_{max}	12.57	cm
y_{max}	125.73	mm

compare

Base Grade	2.0%	
S_1 =	0.020	
Pipe Slope	7.6%	
S_2 =	0.076	
S (tanα)	0.0786	
α =	0.0784	radians
α =	4.493	degrees
sinα	0.0783	
cosα	0.9969	
r	8.29	mm/day
r	0.829	cm/day
k_{eq}	0.1046	cm/sec
k_{eq}	[illegible]	cm/day
b	2897.223	cm
L	11384.28	cm

Giroud's 92 Method

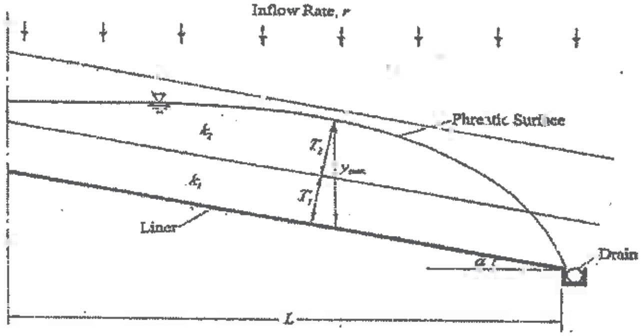
A	0.0965839
B	-1.030364
j	0.8571748

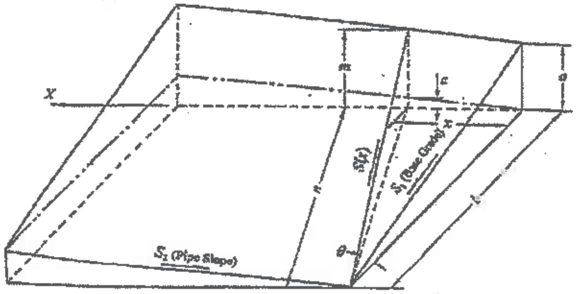
Calculated

y_{max}	12.57	cm
y_{max}	125.73	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-G Phase 2 East Area

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	6.6%	
S_2 =	0.066	

S (tanα)	0.0690	
α =	0.0689	radians
α =	3.945	degrees
sinα	0.0688	
cosα	0.9976	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.74	mm

Assumed

y_{max}	31.07	cm
y_{max}	310.74	mm

compare

input
trial & error
output

Trial 1

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	6.6%	
S_2 =	0.066	

S (tanα)	0.0690	
α =	0.0689	radians
α =	3.945	degrees
sinα	0.0688	
cosα	0.9976	

r	7.32	mm/day
r	0.732	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1968	cm/day

b	3371.36	cm
L	11625.07	cm

Giroud's 92 Method

A	5.1695267
B	0.393679
j	0.953726

Calculated

y_{max}	26.50	cm
y_{max}	265.01	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	6.6%	
S_2 =	0.066	

S (tanα)	0.0690	
α =	0.0689	radians
α =	3.945	degrees
sinα	0.0688	
cosα	0.9976	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	139	mm

k_{eq}	0.927	mm/sec

Assumed

y_{max}	144.20	mm

Assumed

y_{max}	14.42	cm
y_{max}	144.20	mm

compare

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	6.6%	
S_2 =	0.066	

S (tanα)	0.0690	
α =	0.0689	radians
α =	3.945	degrees
sinα	0.0688	
cosα	0.9976	

r	7.32	mm/day
r	0.732	cm/day

k_{eq}	0.0927	cm/sec
k_{eq}	[illegible]	cm/day

b	3371.3568	cm
L	11625.07	cm

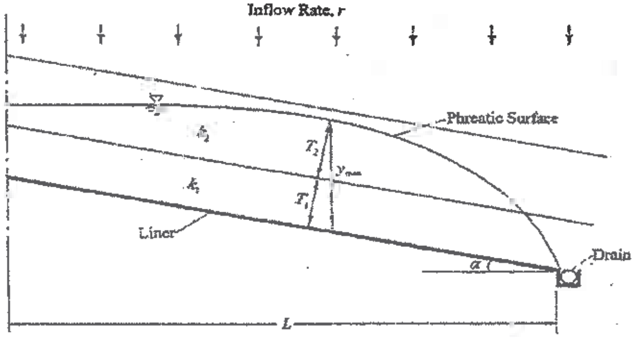
Giroud's 92 Method

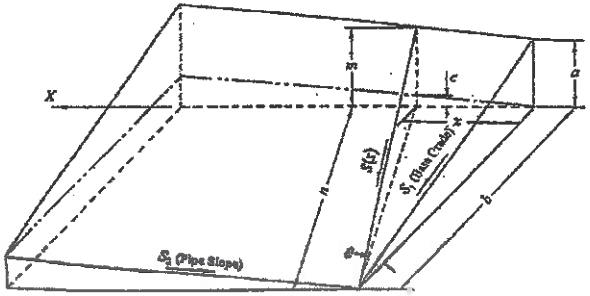
A	0.1135052
B	0.802995
j	0.9598887

Calculated

y_{max}	14.42	cm
y_{max}	144.20	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media ***Developed by Xuede (Dan) Qian*** **2008**





MC VI-G Phase 3 NE Area

Base Grade	2.0%		input
S1 =	0.020		trial & error
			output

Pipe Slope	1.8%	
S_2 =	0.018	

S (tanα)	0.0269	
α =	0.0269	radians
α =	1.541	degrees
sinα	0.0269	
cosα	0.9996	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.11	mm

Assumed

y_{max}	31.01	cm
y_{max}	310.11	mm

compare

Trial 1

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	1.8%	
S_2 =	0.018	

S (tanα)	0.0269	
α =	0.0269	radians
α =	1.541	degrees
sinα	0.0269	
cosα	0.9996	

r	5.97	mm/day
r	0.597	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	4247.93	cm
L	5715.00	cm

Giroud's 92 Method

A	0.4842619
B	-0.099169
j	0.8913286

Calculated

y_{max}	23.00	cm
y_{max}	230.02	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	1.8%	
S_2 =	0.018	

S (tanα)	0.0269	
α =	0.0269	radians
α =	1.541	degrees
sinα	0.0269	
cosα	0.9996	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	84	mm

k_{eq}	1.418	mm/sec

Assumed

y_{max}	89.28	mm

Assumed

y_{max}	8.93	cm
y_{max}	89.28	mm

compare

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	1.8%	
S_2 =	0.018	

S (tanα)	0.0269	
α =	0.0269	radians
α =	1.541	degrees
sinα	0.0269	
cosα	0.9996	

r	5.97	mm/day
r	0.597	cm/day

k_{eq}	0.1418	cm/sec
k_{eq}	12250.31	cm/day

b	4247.926	cm
L	5715.00	cm

Giroud's 92 Method

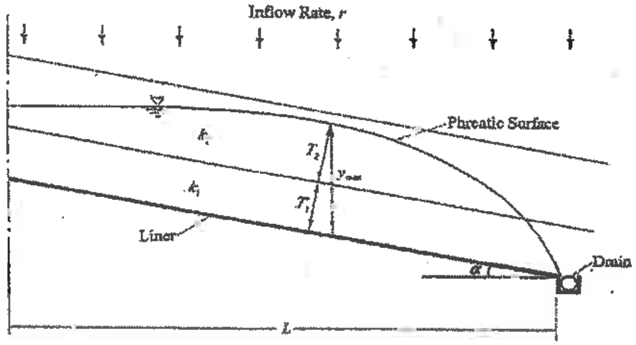
A	0.1243386
B	0.365867
j	0.916769

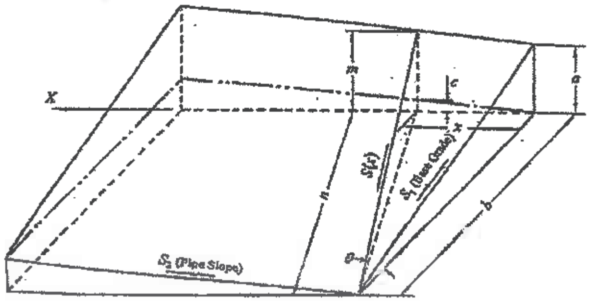
Calculated

y_{max}	8.93	cm
y_{max}	89.28	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-G Phase 3 NW Area

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	5.0%	
S_2 =	0.050	

S (tanα)	0.0539	
α =	0.0538	radians
α =	3.082	degrees
sinα	0.0538	
cosα	0.9986	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.45	mm

Assumed

y_{max}	31.04	cm
y_{max}	310.45	mm

input
trial & error
output

compare

Trial 1

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	5.0%	
S_2 =	0.050	

S (tanα)	0.0539	
α =	0.0538	radians
α =	3.082	degrees
sinα	0.0538	
cosα	0.9986	

r	6.32	mm/day
r	0.632	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4208.1984	cm/day

b	3978.98	cm
L	10713.72	cm

Giroud's 92 Method

A	0.2108148
B	-0.457111
j	0.9240268

Calculated

y_{max}	26.34	cm
y_{max}	263.42	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	5.0%	
S_2 =	0.050	

S (tanα)	0.0539	
α =	0.0538	radians
α =	3.082	degrees
sinα	0.0538	
cosα	0.9986	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	140	mm

k_{eq}	0.918	mm/sec

Assumed

y_{max}	145.54	mm

Assumed

y_{max}	14.55	cm
y_{max}	145.54	mm

compare

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	5.0%	
S_2 =	0.050	

S (tanα)	0.0539	
α =	0.0538	radians
α =	3.082	degrees
sinα	0.0538	
cosα	0.9986	

r	6.32	mm/day
r	0.632	cm/day

k_{eq}	0.0918	cm/sec
k_{eq}	[illegible]	cm/day

b	3978.976	cm
L	10713.72	cm

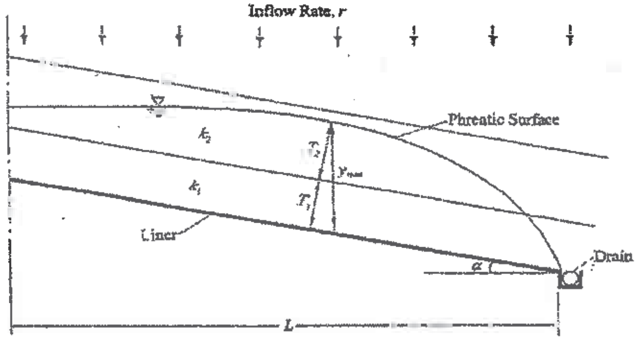
Giroud's 92 Method

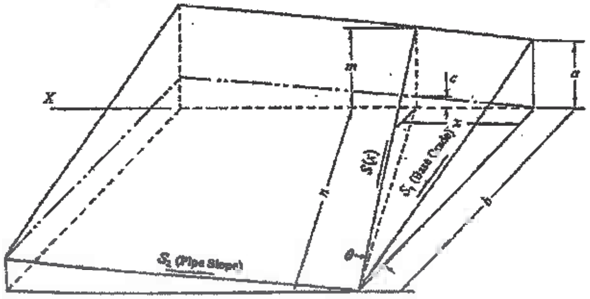
A	0.141856
B	-0.719364
j	0.941553

Calculated

y_{max}	14.55	cm
y_{max}	145.54	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media *Developed by Xuede (Dan) Qian* **2008**





MC VI-G Phase 3 SE Area

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	1.8%	
S_2 =	0.018	

S (tanα)	0.0439	
α =	0.0438	radians
α =	[illegible]	degrees
sinα	0.0438	
cosα	0.9990	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.30	mm

Assumed

y_{max}	31.03	cm
y_{max}	310.30	mm

input
trial & error
output

compare

Trial 1

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	1.8%	
S_2 =	0.018	

S (tanα)	0.0439	
α =	0.0438	radians
α =	[illegible]	degrees
sinα	0.0438	
cosα	0.9990	

r	7.89	mm/day
r	0.789	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1604	cm/day

b	6026.04	cm
L	6608.06	cm

Giroud's 92 Method

A	0.312965
B	0.254524
j	0.9060650

Calculated

y_{max}	23.53	cm
y_{max}	235.32	mm

Trial 2

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	1.8%	
S_2 =	0.018	

S (tanα)	0.0439	
α =	0.0438	radians
α =	2.512	degrees
sinα	0.0438	
cosα	0.9990	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	76	mm

k_{eq}	1.546	mm/sec

Assumed

y_{max}	81.18	mm

Assumed

y_{max}	8.12	cm
y_{max}	81.18	mm

compare

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	1.8%	
S_2 =	0.018	

S (tanα)	0.0439	
α =	0.0438	radians
α =	2.512	degrees
sinα	0.0438	
cosα	0.9990	

r	7.89	mm/day
r	0.789	cm/day

k_{eq}	0.1546	cm/sec
k_{eq}	13357.41	cm/day

b	6026.036	cm
L	6608.06	cm

Giroud's 92 Method

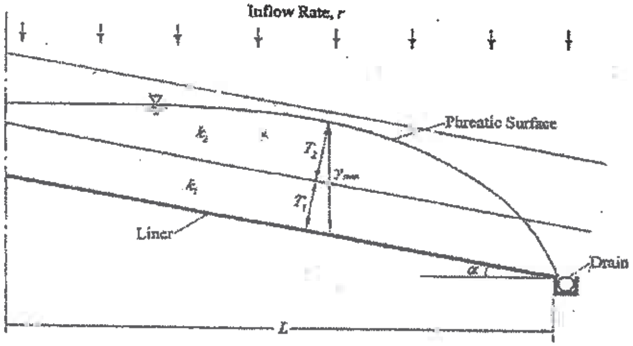
A	0.15207
B	0.669053
j	0.938537

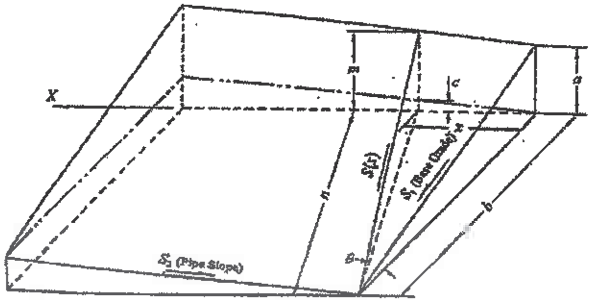
Calculated

y_{max}	8.12	cm
y_{max}	81.18	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-G Phase 3 SW Area

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	5.0%	
S_2 =	0.050	

S (tanα)	0.0640	
α =	0.0639	radians
α =	3.664	degrees
sinα	0.0639	
cosα	0.9980	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.63	mm

Assumed

y_{max}	31.06	cm
y_{max}	310.63	mm

compare

input
trial & error
output

Trial 1

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	5.0%	
S_2 =	0.050	

S (tanα)	0.0640	
α =	0.0639	radians
α =	3.662	degrees
sinα	0.0639	
cosα	0.9980	

r	8.09	mm/day
r	0.809	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	5615.10	cm
L	8988.55	cm

Giroud's 92 Method

A	0.1981202
B	-0.494309
j	0.9268009

Calculated

y_{max}	23.98	cm
y_{max}	239.81	mm

Trial 2

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	5.0%	
S_2 =	0.050	

S (tanα)	0.0640	
α =	0.0639	radians
α =	3.664	degrees
sinα	0.0639	
cosα	0.9980	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	69	mm

k_{eq}	1.670	mm/sec

Assumed

y_{max}	74.64	mm

Assumed

y_{max}	7.46	cm
y_{max}	74.64	mm

compare

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	5.0%	
S_2 =	0.050	

S (tanα)	0.0640	
α =	0.0639	radians
α =	3.664	degrees
sinα	0.0639	
cosα	0.9980	

r	8.09	mm/day
r	0.809	cm/day

k_{eq}	0.1670	cm/sec
k_{eq}	14428.8	cm/day

b	5615.104	cm
L	8988.55	cm

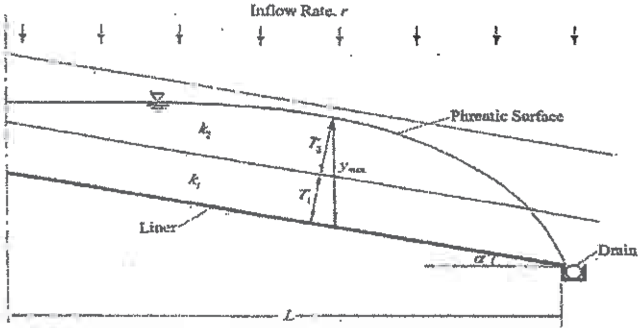
Giroud's 92 Method

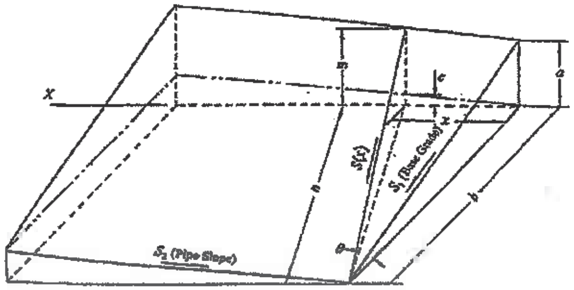
A	0.0591784
B	-1.076334
j	0.959918

Calculated

y_{max}	7.46	cm
y_{max}	74.64	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media *Developed by Xuede (Dan) Qian* 2008





MC VI-G Phase 4 NE Area

Base Grade	5.5%	
S₁ =	0.055	

input
trial & error
output

Pipe Slope	1.5%	
S₂ =	0.015	

S (tanα)	0.0570	
α =	0.0569	radians
α =	3.263	degrees
sinα	0.0569	
cosα	0.9984	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.50	mm

Assumed

y_{max}	31.05	cm
y_{max}	310.50	mm

compare

Trial 1

Base Grade	5.5%	
S₁ =	0.055	

Pipe Slope	1.5%	
S₂ =	0.015	

S (tanα)	0.0570	
α =	0.0569	radians
α =	3.263	degrees
sinα	0.0569	
cosα	0.9984	

r	9.27	mm/day
r	0.927	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4208.1904	cm/day

b	6095.86	cm
L	6318.50	cm

Giroud's 92 Method

A	0.24943
B	0.363671
j	0.9165856

Calculated

y_{max}	21.07	cm
y_{max}	210.67	mm

Trial 2

Base Grade	5.5%	
S₁ =	0.055	

Pipe Slope	1.5%	
S₂ =	0.015	

S (tanα)	0.0570	
α =	0.0569	radians
α =	3.263	degrees
sinα	0.0569	
cosα	0.9984	

$k1$	12.2	mm/sec
$k2$	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	26	mm

k_{eq}	3.734	mm/sec

Assumed

y_{max}	30.62	mm

Assumed

y_{max}	3.06	cm
y_{max}	30.62	mm

compare

Base Grade	5.5%	
S₁ =	0.055	

Pipe Slope	1.5%	
S₂ =	0.015	

S (tanα)	0.0570	
α =	0.0569	radians
α =	3.263	degrees
sinα	0.0569	
cosα	0.9984	

r	9.27	mm/day
r	0.927	cm/day

k_{eq}	0.3734	cm/sec
k_{eq}	32261.64	cm/day

b	6095.864	cm
L	6318.50	cm

Giroud's 92 Method

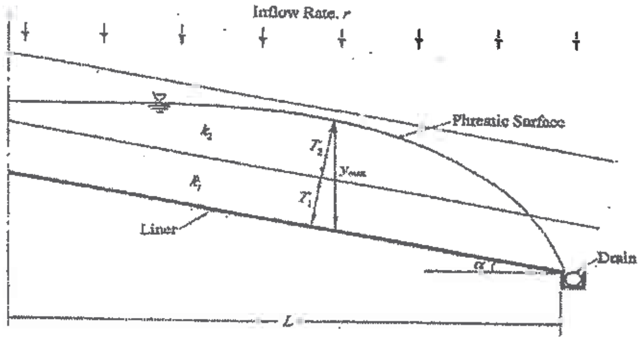
A	0.963846
B	1.333902
j	0.968463

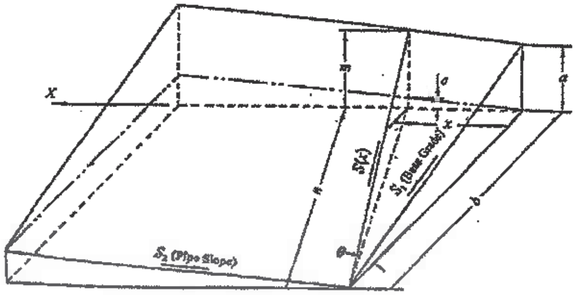
Calculated

y_{max}	3.06	cm
y_{max}	30.62	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-G Phase 4 NW Area

Base Grade	5.5%	
S₁ =	0.055	

Pipe Slope	3.1%	
S₂ =	0.031	

S (tanα)	0.0631	
α =	0.0631	radians
α =	3.613	degrees
sinα	0.0630	
cosα	0.9980	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.62	mm

Assumed

y_{max}	31.06	cm
y_{max}	310.62	mm

compare

input
trial & error
output

Trial 1

Base Grade	5.5%	
S₁ =	0.055	

Pipe Slope	3.1%	
S₂ =	0.031	

S (tanα)	0.0631	
α =	0.0631	radians
α =	3.613	degrees
sinα	0.0630	
cosα	0.9980	

r	9.25	mm/day
r	0.925	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.9904	cm/day

b	6107.13	cm
L	7010.40	cm

Giroud's 92 Method

A	0.2192571
B	0.434342
j	0.922271

Calculated

y_{max}	21.43	cm
y_{max}	214.27	mm

Trial 2

Base Grade	5.5%	
S₁ =	0.055	

Pipe Slope	3.1%	
S₂ =	0.031	

S (tanα)	0.0631	
α =	0.0631	radians
α =	3.613	degrees
sinα	0.0630	
cosα	0.9980	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	27	mm

k_{eq}	3.605	mm/sec

Assumed

y_{max}	31.87	mm

Assumed

y_{max}	3.19	cm
y_{max}	31.87	mm

compare

Base Grade	5.5%	
S₁ =	0.055	

Pipe Slope	3.1%	
S₂ =	0.031	

S (tanα)	0.0631	
α =	0.0631	radians
α =	3.613	degrees
sinα	0.0630	
cosα	0.9980	

r	9.25	mm/day
r	0.925	cm/day

k_{eq}	0.3605	cm/sec
k_{eq}	31151.34	cm/day

b	6107.125	cm
L	7010.40	cm

Giroud's 92 Method

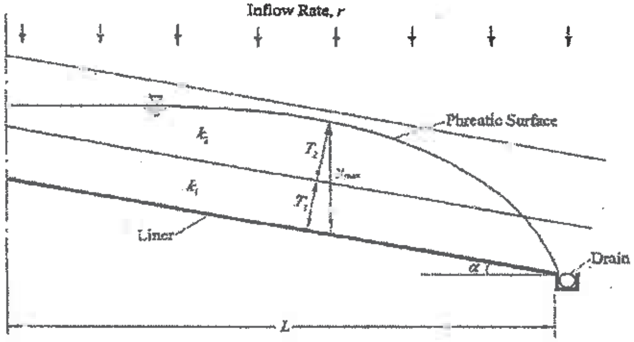
A	0.062757
B	1.445623
j	0.971728

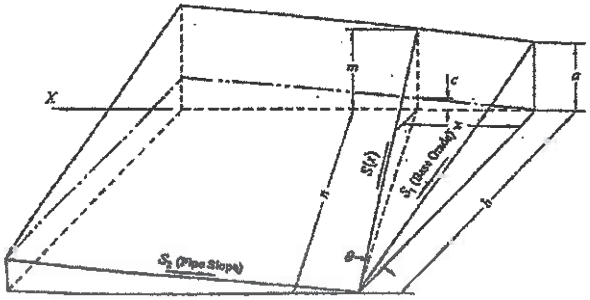
Calculated

y_{max}	3.19	cm
y_{max}	31.87	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-G Phase 4 SE Area

Base Grade	4.0%	
S_1 =	0.040	

input
trial & error
output

Pipe Slope	1.5%	
S_2 =	0.015	

S (tanα)	0.0427	
α =	0.0427	radians
α =	2.446	degrees
sinα	0.0427	
cosα	0.9991	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.28	mm

Assumed

y_{max}	31.03	cm
y_{max}	310.28	mm

compare

Trial 1

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	1.5%	
S_2 =	0.015	

S (tanα)	0.0427	
α =	0.0427	radians
α =	2.446	degrees
sinα	0.0427	
cosα	0.9991	

r	8.89	mm/day
r	0.889	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	5060.02	cm
L	5404.10	cm

Giroud's 92 Method

A	0.348518
B	-0.209559
j	0.9026869

Calculated

y_{max}	21.85	cm
y_{max}	218.5	mm

Trial 2

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	1.5%	
S_2 =	0.015	

S (tanα)	0.0427	
α =	0.0427	radians
α =	2.446	degrees
sinα	0.0427	
cosα	0.9991	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	46	mm

k_{eq}	2.350	mm/sec

Assumed

y_{max}	51.21	mm

Assumed

y_{max}	5.12	cm
y_{max}	51.21	mm

compare

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	1.5%	
S_2 =	0.015	

S (tanα)	0.0427	
α =	0.0427	radians
α =	2.446	degrees
sinα	0.0427	
cosα	0.9991	

r	8.89	mm/day
r	0.889	cm/day

k_{eq}	0.2350	cm/sec
k_{eq}	20299.76	cm/day

b	5060.02	cm
L	5404.10	cm

Giroud's 92 Method

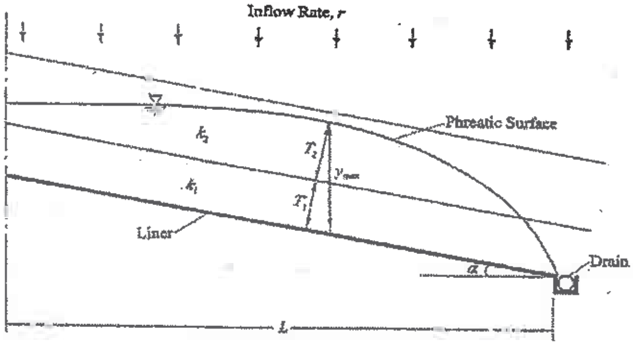
A	0.130967
B	-0.762929
j	0.045152

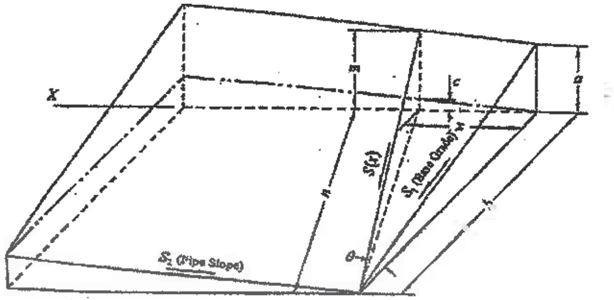
Calculated

y_{max}	5.12	cm
y_{max}	51.21	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-G Phase 4 SW Area

Base Grade	4.0%	
S₁ =	0.040	

Pipe Slope	3.1%	
S₂ =	0.031	

S (tanα)	0.0506	
α =	0.0506	radians
α =	2.897	degrees
sinα	0.0505	
cosα	0.9987	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.40	mm

Assumed

y_{max}	31.04	cm
y_{max}	310.40	mm

compare

input
trial & error
output

Trial 1

Base Grade	4.0%	
S₁ =	0.040	

Pipe Slope	3.1%	
S₂ =	0.031	

S (tanα)	0.0506	
α =	0.0505	radians
α =	2.897	degrees
sinα	0.0505	
cosα	0.9987	

r	8.93	mm/day
r	0.893	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	5003.88	cm
L	6330.70	cm

Giroud's 92 Method

A	0.2827985
B	-0.300877
j	0.9111798

Calculated

y_{max}	22.48	cm
y_{max}	224.84	mm

Trial 2

Base Grade	4.0%	
S₁ =	0.040	

Pipe Slope	3.1%	
S₂ =	0.031	

S (tanα)	0.0506	
α =	0.0506	radians
α =	2.897	degrees
sinα	0.0505	
cosα	0.9987	

$k1$	12.2	mm/sec
$k2$	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	50	mm

k_{eq}	2.211	mm/sec

Assumed

y_{max}	54.78	mm

Assumed

y_{max}	5.48	cm
y_{max}	54.78	mm

compare

Base Grade	4.0%	
S₁ =	0.040	

Pipe Slope	3.1%	
S₂ =	0.031	

S (tanα)	0.0506	
α =	0.0506	radians
α =	2.897	degrees
sinα	0.0505	
cosα	0.9987	

r	8.93	mm/day
r	0.893	cm/day

k_{eq}	0.2211	cm/sec
k_{eq}	[illegible]	cm/day

b	5003.877	cm
L	6330.70	cm

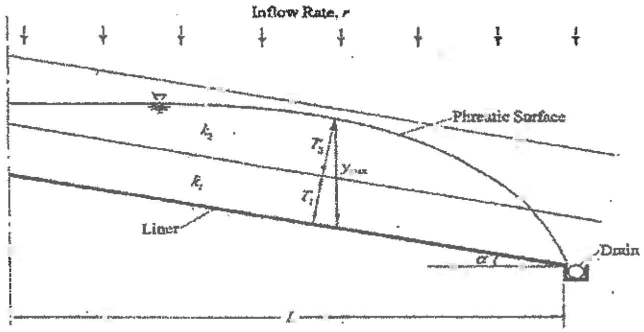
Giroud's 92 Method

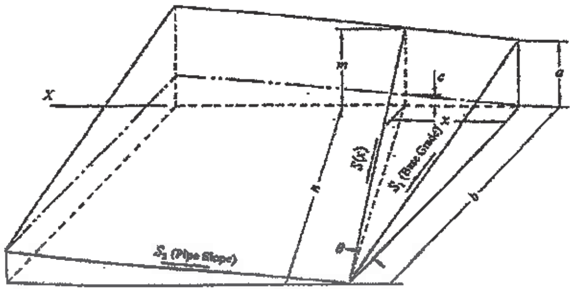
A	0.109591
B	-0.919752
j	-3.352166

Calculated

y_{max}	5.48	cm
y_{max}	54.78	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media ***Developed by Xuede (Dan) Qian*** **2008**





MC VI-G Phase 5 NE Area

Base Grade	2.0%	
S₁ =	0.020	

Pipe Slope	8.0%	
S₂ =	0.080	

S (tanα)	0.0825	
α =	0.0823	radians
α =	4.[illegible]	degrees
sinα	0.0822	
cosα	0.9966	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	311.05	mm

Assumed

y_{max}	31.11	cm
y_{max}	311.05	mm

input
trial & error
output

compare

Trial 1

Base Grade	2.0%	
S₁ =	0.020	

Pipe Slope	8.0%	
S₂ =	0.080	

S (tanα)	0.0825	
α =	0.0823	radians
α =	4.716	degrees
sinα	0.0822	
cosα	0.9966	

r	9.21	mm/day
r	0.921	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4206[illegible]904	cm/day

b	1228.63	cm
L	5065.78	cm

Giroud's 92 Method

A	0.1566012
B	-0.648355
j	0.9372514

Calculated

y_{max}	12.26	cm
y_{max}	122.58	mm

Trial 2

Base Grade	2.0%	
S₁ =	0.020	

Pipe Slope	8.0%	
S₂ =	0.080	

S (tanα)	0.0825	
α =	0.0823	radians
α =	4.716	degrees
sinα	0.0822	
cosα	0.9966	

$k1$	12.2	mm/sec
$k2$	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	0	mm

k_{eq}	12.150	mm/sec

Assumed

y_{max}	5.36	mm

Assumed

y_{max}	0.54	cm
y_{max}	5.36	mm

compare

Base Grade	2.0%	
S₁ =	0.020	

Pipe Slope	8.0%	
S₂ =	0.080	

S (tanα)	0.0825	
α =	0.0823	radians
α =	4.724	degrees
sinα	0.0822	
cosα	0.9966	

r	9.21	mm/day
r	0.921	cm/day

k_{eq}	1.2150	cm/sec
k_{eq}	104974.4	cm/day

b	1228.631	cm
L	5065.78	cm

Giroud's 92 Method

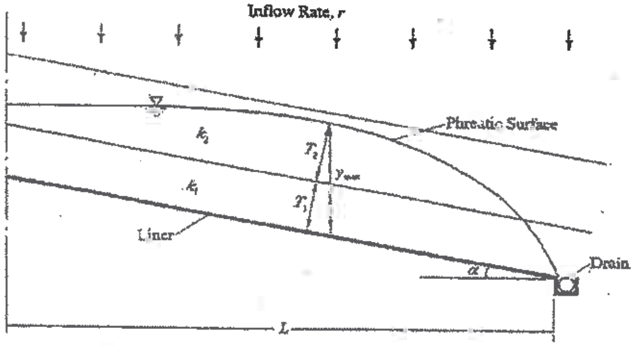
A	0.020977
B	-2.81655
j	0.982823

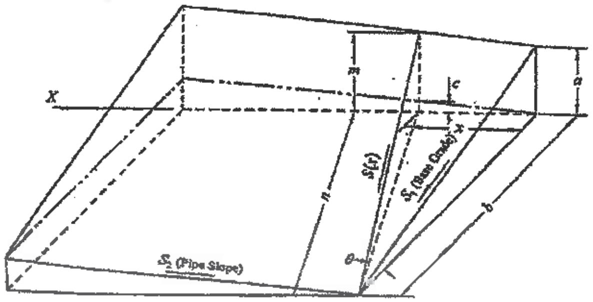
Calculated

y_{max}	0.54	cm
y_{max}	5.36	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-G Phase 5 NW Area

Base Grade	2.0%	
S_1 =	0.020	

input
trial & error
output

Pipe Slope	2.5%	
S_2 =	0.025	

S (tanα)	0.0320	
α =	0.0320	radians
α =	1.834	degrees
sinα	0.0320	
cosα	0.9995	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.16	mm

Assumed

y_{max}	31.02	cm
y_{max}	310.16	mm

compare

Trial 1

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	2.5%	
S_2 =	0.025	

S (tanα)	0.0320	
α =	0.0320	radians
α =	1.834	degrees
sinα	0.0320	
cosα	0.9995	

r	5.4	mm/day
r	0.54	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1504	cm/day

b	4765.89	cm
L	7629.14	cm

Giroud's 92 Method

A	0.3650114
B	-0.190537
j	0.9008182

Calculated

y_{max}	24.77	cm
y_{max}	247.67	mm

Trial 2

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	2.5%	
S_2 =	0.025	

S (tanα)	0.0320	
α =	0.0320	radians
α =	1.834	degrees
sinα	0.0320	
cosα	0.9995	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	114	mm

k_{eq}	1.093	mm/sec

Assumed

y_{max}	119.39	mm

Assumed

y_{max}	11.94	cm
y_{max}	119.39	mm

compare

Base Grade	2.0%	
S_1 =	0.020	

Pipe Slope	2.5%	
S_2 =	0.025	

S (tanα)	0.0320	
α =	0.0320	radians
α =	1.834	degrees
sinα	0.0320	
cosα	0.9995	

r	5.4	mm/day
r	0.54	cm/day

k_{eq}	0.1093	cm/sec
k_{eq}	9441.196	cm/day

b	4765.888	cm
L	7629.14	cm

Giroud's 92 Method

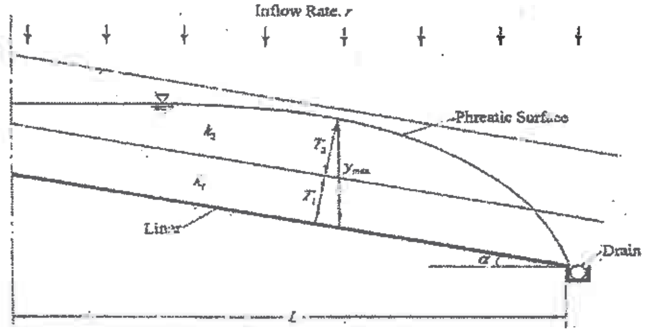
A	0.220814
B	0.430038
j	0.921942

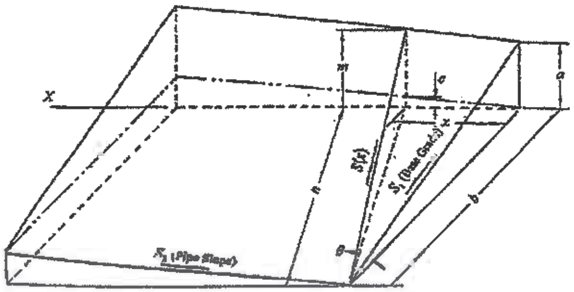
Calculated

y_{max}	11.94	cm
y_{max}	119.39	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-G Phase 5 SE Area

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	8.0%	
S_2 =	0.080	

S (tanα)	0.0894	
α =	0.089[illegible]	radians
α =	5.11[illegible]	degrees
sinα	0.089[illegible]	
cosα	0.9960	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	311.24	mm

Assumed

y_{max}	31.12	cm
y_{max}	311.24	mm

compare

input
trial & error
output

Trial 1

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	8.0%	
S_2 =	0.080	

S (tanα)	0.0894	
α =	[illegible]	radians
α =	[illegible]	degrees
sinα	[illegible]	
cosα	[illegible]	

r	10.13	mm/day
r	1.013	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	[illegible]	cm/day

b	2604.90	cm
L	5824.73	cm

Giroud's 92 Method

A	0.1501501
B	-0.078411
j	0.039091

Calculated

y_{max}	14.36	cm
y_{max}	143.57	mm

Trial 2

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	8.0%	
S_2 =	0.080	

S (tanα)	0.0894	
α =	[illegible]	radians
α =	[illegible]	degrees
sinα	[illegible]	
cosα	[illegible]	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	2	mm

k_{eq}	11.500	mm/sec

Assumed

y_{max}	6.61	mm

Assumed

y_{max}	0.66	cm
y_{max}	6.61	mm

compare

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	8.0%	
S_2 =	0.080	

S (tanα)	0.0894	
α =	0.0862	radians
α =	5.111	degrees
sinα	0.0891	
cosα	0.9960	

r	10.13	mm/day
r	1.013	cm/day

k_{eq}	1.1500	cm/sec
k_{eq}	99356.99	cm/day

b	2604.898	cm
L	5824.73	cm

Giroud's 92 Method

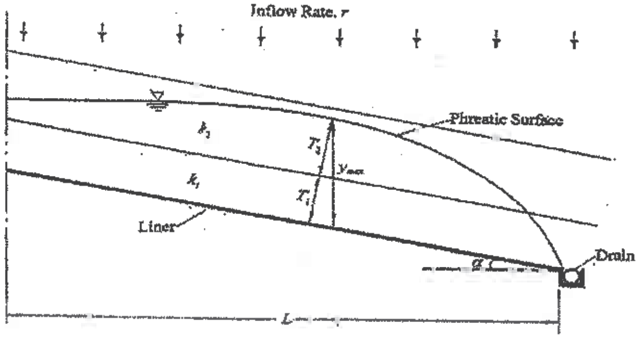
A	0.020816
B	2.327767
j	0.992903

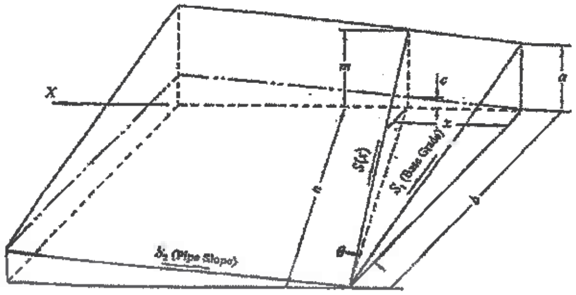
Calculated

y_{max}	0.66	cm
y_{max}	6.61	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-G Phase 5 SW Area

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	2.5%	
S_2 =	0.025	

S (tanα)	0.0472	
α =	0.0471	radians
α =	2.701	degrees
sinα	0.0471	
cosα	0.9989	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.34	mm

Assumed

y_{max}	31.03	cm
y_{max}	310.34	mm

input
trial & error
output

compare

Trial 1

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	2.5%	
S_2 =	0.025	

S (tanα)	0.0472	
α =	0.0471	radians
α =	2.701	degrees
sinα	0.0471	
cosα	0.9989	

r	8.2	mm/day
r	0.82	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	[illegible]	cm/day

b	5753.54	cm
L	6784.85	cm

Giroud's 92 Method

A	0.29275[illegible]
B	0.284619
j	0.9097233

Calculated

y_{max}	23.61	cm
y_{max}	236.05	mm

Trial 2

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	2.5%	
S_2 =	0.025	

S (tanα)	0.0472	
α =	0.0471	radians
α =	2.701	degrees
sinα	0.0471	
cosα	0.9989	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	75	mm

k_{eq}	1.564	mm/sec

Assumed

y_{max}	80.18	mm

Assumed

y_{max}	8.02	cm
y_{max}	80.18	mm

compare

Base Grade	4.0%	
S_1 =	0.040	

Pipe Slope	2.5%	
S_2 =	0.025	

S (tanα)	0.0472	
α =	0.0471	radians
α =	2.701	degrees
sinα	0.0471	
cosα	0.9989	

r	8.2	mm/day
r	0.82	cm/day

k_{eq}	0.1564	cm/sec
k_{eq}	[illegible]	cm/day

b	5753.54	cm
L	6784.85	cm

Giroud's 92 Method

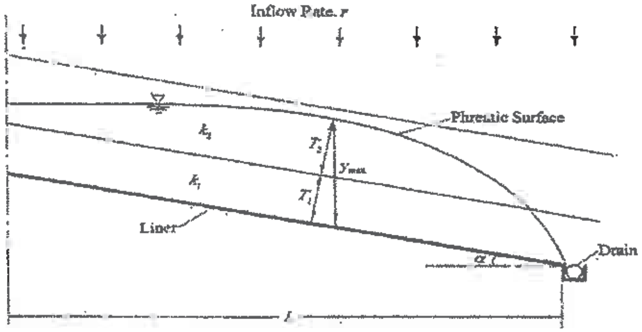
A	0.141245
B	0.722548
j	0.941738

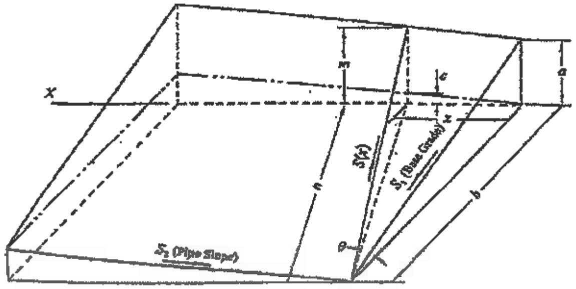
Calculated

y_{max}	8.02	cm
y_{max}	80.18	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian 2008





MC VI-G Phase 6 NE Area

Base Grade	5.8%	
S_1 =	0.058	

Pipe Slope	6.1%	
S_2 =	0.061	

S (tanα)	0.0842	
α =	0.0840	radians
α =	4.811	degrees
sinα	0.0839	
cosα	0.9965	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	311.10	mm

Assumed

y_{max}	31.11	cm
y_{max}	311.10	mm

input
trial & error
output

compare

Trial 1

Base Grade	5.8%	
S_1 =	0.058	

Pipe Slope	6.1%	
S_2 =	0.061	

S (tanα)	0.0842	
α =	0.0840	radians
α =	4.811	degrees
sinα	0.0839	
cosα	0.9965	

r	9.91	mm/day
r	0.991	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4208.1904	cm/day

b	3782.11	cm
L	5488.78	cm

Giroud's 92 Method

A	0.1467844
B	-0.634357
j	0.9363669

Calculated

y_{max}	13.98	cm
y_{max}	139.77	mm

Trial 2

Base Grade	5.8%	
S_1 =	0.058	

Pipe Slope	6.1%	
S_2 =	0.061	

S (tanα)	0.0842	
α =	0.0840	radians
α =	4.811	degrees
sinα	0.0839	
cosα	0.9965	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	1	mm

k_{eq}	11.643	mm/sec

Assumed

y_{max}	6.39	mm

Assumed

y_{max}	0.64	cm
y_{max}	6.39	mm

compare

Base Grade	5.8%	
S_1 =	0.058	

Pipe Slope	6.1%	
S_2 =	0.061	

S (tanα)	0.0842	
α =	0.0840	radians
α =	[illegible]	degrees
sinα	0.0839	
cosα	0.9965	

r	9.91	mm/day
r	0.991	cm/day

k_{eq}	1.1643	cm/sec
k_{eq}	100695.9	cm/day

b	3782.109	cm
L	5488.78	cm

Giroud's 92 Method

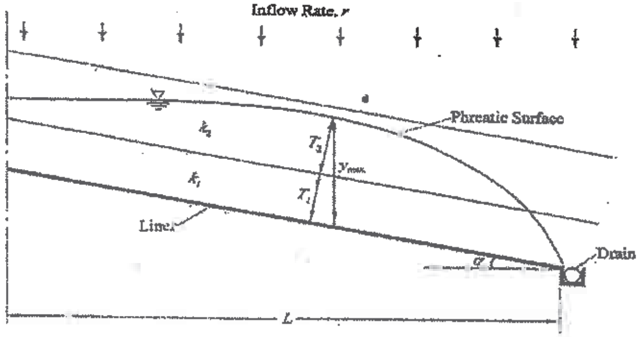
A	0.1[illegible]961
B	-2.748812
j	0.99232

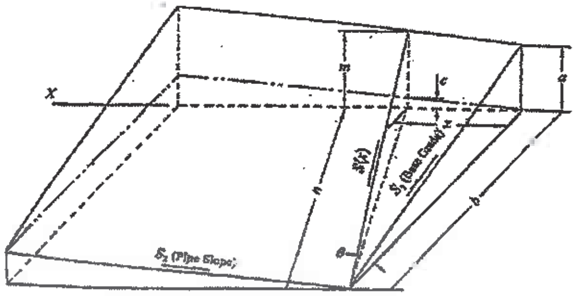
Calculated

y_{max}	0.64	cm
y_{max}	6.39	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-G Phase 6 NW Area

Base Grade	5.8%	
S_1 =	0.058	

Pipe Slope	3.7%	
S_2 =	0.037	

S (tanα)	0,0688	
α =	0.0687	radians
α =	3.936	degrees
sinα	0.0686	
cosα	0.9976	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.73	mm

Assumed

y_{max}	31.07	cm
y_{max}	310.73	mm

compare

input
trial & error
output

Trial 1

Base Grade	5.8%	
S_1 =	0.058	

Pipe Slope	3.7%	
S_2 =	0.037	

S (tanα)	0.0688	
α =	0.0687	radians
α =	3.936	degrees
sinα	0.0686	
cosα	0.9976	

r	9.48	mm/day
r	0.948	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	42[illegible]904	cm/day

b	5722.62	cm
L	6787.90	cm

Giroud's 92 Method

A	0.1999842
B	0.488607
j	0.9263823

Calculated

y_{max}	19.74	cm
y_{max}	197.36	mm

Trial 2

Base Grade	5.8%	
S_1 =	0.058	

Pipe Slope	3.7%	
S_2 =	0.037	

S (tanα)	0.0688	
α =	0.0687	radians
α =	3.936	degrees
sinα	0.0686	
cosα	0.9976	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	13	mm

k_{eq}	5.915	mm/sec

Assumed

y_{max}	17.94	mm

Assumed

y_{max}	1.79	cm
y_{max}	17.94	mm

compare

Base Grade	5.8%	
S_1 =	0.058	

Pipe Slope	3.7%	
S_2 =	0.037	

S (tanα)	0.0688	
α =	0.0687	radians
α =	3.936	degrees
sinα	0.0686	
cosα	0.9976	

r	9.48	mm/day
r	0.948	cm/day

k_{eq}	0.5915	cm/sec
k_{eq}	51106.5	cm/day

b	5722.62	cm
L	6787.90	cm

Giroud's 92 Method

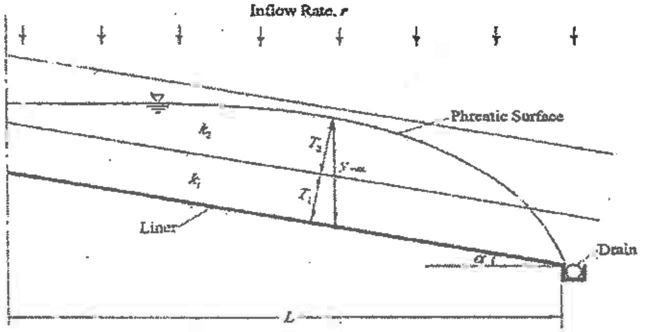
A	0.042667
B	-1.895248
j	0.991965

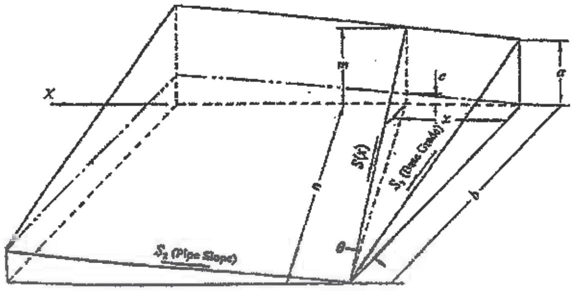
Calculated

y_{max}	1.79	cm
y_{max}	17.93	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-G Phase 6 SE Area

Base Grade	3.0%	
S_1 =	0.030	

Pipe Slope	6.1%	
S_2 =	0.061	

S (tanα)	0.0680	
α =	0.0679	radians
α =	3.889	degrees
sinα	0.0678	
cosα	0.9977	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.72	mm

Assumed

y_{max}	31.07	cm
y_{max}	310.72	mm

compare

input
trial & error
output

Trial 1

Base Grade	3.0%	
S_1 =	0.030	

Pipe Slope	6.1%	
S_2 =	0.061	

S (tanα)	0.0680	
α =	[illegible]	radians
α =	[illegible]	degrees
sinα	0.0678	
cosα	0.9977	

r	9.57	mm/day
r	0.957	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1901	cm/day

b	2236.77	cm
L	5068.36	cm

Giroud's 92 Method

A	0.2042024
B	-0.478016
j	0.9254496

Calculated

y_{max}	15.02	cm
y_{max}	150.18	mm

Trial 2

Base Grade	3.0%	
S_1 =	0.030	

Pipe Slope	6.1%	
S_2 =	0.061	

S (tanα)	0.0680	
α =	0.0679	radians
α =	3.889	degrees
sinα	0.0678	
cosα	0.9977	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	3	mm

k_{eq}	10.850	mm/sec

Assumed

y_{max}	7.52	mm

Assumed

y_{max}	0.75	cm
y_{max}	7.52	mm

compare

Base Grade	3.0%	
S_1 =	0.030	

Pipe Slope	6.1%	
S_2 =	0.061	

S (tanα)	0.0680	
α =	0.0679	radians
α =	3.889	degrees
sinα	0.0678	
cosα	0.9977	

r	9.57	mm/day
r	0.957	cm/day

k_{eq}	1.0850	cm/sec
k_{eq}	93745.45	cm/day

b	2236.769	cm
L	5068.36	cm

Giroud's 92 Method

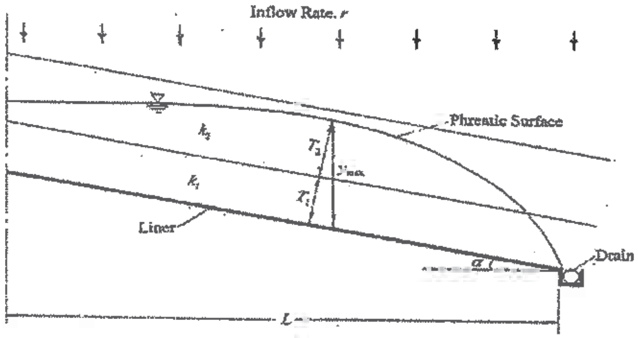
A	0.029367
B	-2.347894
j	0.986532

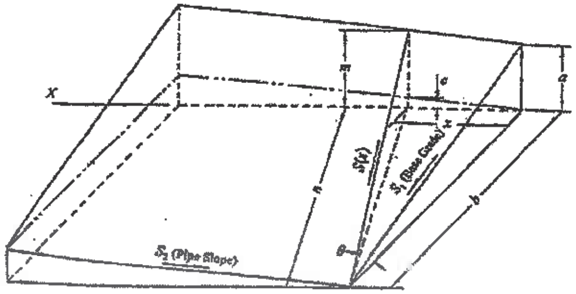
Calculated

y_{max}	0.75	cm
y_{max}	7.52	mm

Maximum Leachate Head Calculation in Two-Layer Drainage Media

Developed by Xuede (Dan) Qian **2008**





MC VI-G Phase 6 SW Area

Base Grade	3.0%	
S_1 =	0.030	

Pipe Slope	3.7%	
S_2 =	0.037	

S (tanα)	0.0476	
α =	0.0476	radians
α =	2.727	degrees
sinα	0.0476	
cosα	0.9989	

k_1	12.2	mm/sec
k_2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	305	mm

k_{eq}	0.487	mm/sec

Assumed

y_{max}	310.35	mm

Assumed

y_{max}	31.04	cm
y_{max}	310.35	mm

compare

input
trial & error
output

Trial 1

Base Grade	3.0%	
S_1 =	0.030	

Pipe Slope	3.7%	
S_2 =	0.037	

S (tanα)	0.0476	
α =	0.0476	radians
α =	2.727	degrees
sinα	0.0476	
cosα	0.9989	

r	7.52	mm/day
r	0.752	cm/day

k_{eq}	0.0487	cm/sec
k_{eq}	4209.1904	cm/day

b	4958.42	cm
L	7872.98	cm

Giroud's 92 Method

A	0.2739621
B	-0.216169
j	0.9125297

Calculated

y_{max}	25.13	cm
y_{max}	251.33	mm

Trial 2

Base Grade	3.0%	
S_1 =	0.030	

Pipe Slope	3.7%	
S_2 =	0.037	

S (tanα)	0.0476	
α =	0.0476	radians
α =	2.727	degrees
sinα	0.0476	
cosα	0.9989	

k1	12.2	mm/sec
k2	0.1	mm/sec

T_1	5	mm
$(T_2)_{assumed}$	113	mm

k_{eq}	1.108	mm/sec

Assumed

y_{max}	117.64	mm

Assumed

y_{max}	11.76	cm
y_{max}	117.64	mm

compare

Base Grade	3.0%	
S_1 =	0.030	

Pipe Slope	3.7%	
S_2 =	0.037	

S (tanα)	0.0476	
α =	0.0476	radians
α =	2.727	degrees
sinα	0.0476	
cosα	0.9989	

r	7.52	mm/day
r	0.752	cm/day

k_{eq}	0.1108	cm/sec
k_{eq}	9573.319	cm/day

b	4958.421	cm
L	7872.98	cm

Giroud's 92 Method

A	0.163946
B	0.010685
j	0.035232

Calculated

y_{max}	11.76	cm
y_{max}	117.64	mm

Attachment B: 2018 Permit Engineering Drawings

Revision D, May 8, 2018

Submitted Under Separate Cover

Attachment C: Correspondence Regarding the WDI 2018 Permit Modification

Revision 1, May 16, 2018

Question Date	Question From MDEQ/U.S. EPA Region 5	Answer from Wayne Disposal, Inc./CTI and Associates, Inc.	Corresponding information in the 2018 Permit Modification Request
4/5/2018	How will the different liners for different landfill cells be tied together or combined?	Liner tie-ins are detailed in the Permit Engineering Drawings	Attachment B, Permit Engineering Drawings
4/5/2018	What is the thickness of the HDPE plastic liner under the leachate collection system? At on-site meeting, Jim thought he heard that something less than 80 mil HDPE was going to be used.	The thickness for both primary and secondary geomembrane will be 80-mil HDPE geomembrane.	2018 Permit Modification Letter Report Figure 2 and Attachment B, Permit Engineering Drawings
4/5/2018	Attenuation layer at 1.0 x 10^{-5} permeability. When combined with the two GCL layers, how long will it take waste to travel through liner?	This is a complicated question that does not have a definitive answer. As shown in this submittal, when “comparing apples to apples”, the proposed liner system will be at least equivalent to (if not superior than) the current liner system in this regard.	2018 Permit Modification Letter Report section titled "Equivalency Demonstration"
4/5/2018	Steady state solute flux table from presentation shows a “composite permeability” number. Uncertain how this was arrived at or how valid it is for answering the question in third bullet. Also, did MDEQ have some questions about this table?	Composite permeability (or “equivalent” permeability”) is a weighted average of permeability of a system consisting of a number of horizontal layers having different permeabilities and thicknesses. CTI will use the equivalent permeability of the two GCL layers (excluding the flow retardation provided by the attenuation layer for conservatism) to demonstrate that the steady-state solute flux of the proposed liner system is equivalent to (if not superior than) the current liner system in this regard.	2018 Permit Modification Letter Report section titled "Equivalency Demonstration"
4/5/2018	Is geogrid sufficient to prevent damage to landfill structure?	In general, geogrid helps to increase the stiffness of the subgrade and reduce localized subsidence. Additionally, GCL is added to the MC VI-G Phase 2 liner with this proposed permit modification. GCL is well known for its superior capability to endure settlement induced tensioning. Dr. Qian of the MDEQ stated in his book [“Geotechnical aspects of landfill design and construction”. New Jersey: Prentice Hall Inc. (2001)] that a compacted clay liner can only tolerate settlement induced strain of 0.1 to 4% whereas geocomposite clay liner can tolerate 5 - 16% strain. There are no proposed changes to the geogrid already approved by the EPA and MDEQ.	N/A
4/5/2018	Need Cross-Sections in design package that not only show the new proposed design but that also show the old design and landfill design below the new cells. We think there should be at least three cross-sections as follows: -General cross-section showing liner below old landfill cell all the way up to the cap of the new proposed design. - Detailed cross-section of previously approved design for new landfill cell. -Detailed cross-section of design modification for new landfill cell.	The revised Permit Engineering Drawings include cross-sectional views of both the old design and the new design.	Attachment B, Permit Engineering Drawings
4/5/2018	Comparison of leachate collection system between design modification and previously approved design.	The leachate collection system in this proposed permit modification has not changed from the currently permitted system. This proposed permit modification includes the addition of GCL in the baseliner of Master Cell VI-G Phase 2 but does not modify other components of the leachate collection system.	Attachment B, Permit Engineering Drawings
4/5/2018	In summary, the landfill design modification should be at least comparable to the old design modification regarding protectiveness.	The 2018 Permit Modification Letter Report discusses the equivalency of the permit modification.	2018 Permit Modification Letter Report section titled "Equivalency Demonstration"
4/13/2018	We're assuming that the Engineering design will also include the specifications, not just the drawings (schematics). We would like to see what materials/vendors they specify if possible.	This proposed permit modification includes the addition of Geosynthetic Clay Liner (GCL) in the base liner of Master Cell VI-G Phase 2. Distinct GCL products from the manufacturer, CETCO, have been specified in this request and are detailed in the 2018 Permit Modification Letter Report and on the accompanying Permit Engineering Drawings.	2018 Permit Modification Letter Report Figure 2 and Attachment B, Permit Engineering Drawings

Question Date	Question From MDEQ/U.S. EPA Region 5	Answer from Wayne Disposal, Inc./CTI and Associates, Inc.	Corresponding information in the 2018 Permit Modification Request
4/13/2018	Will the cover system also be revised from the original design? A. If so, was that included in the overall slope stability analysis? B. Will the specific materials of the revised material be identified? When?	No. The cover system will remain unchanged as a part of this proposed permit modification.	N/A
4/13/2018	How Did the slope stability analysis results differ from the original design?	The proposed base liner system does not introduce any interface that is more critical (lower) than what is in the permitted liner system. The stability of the permitted liner system was demonstrated in the 2011 permit submittal. In addition, all of the GCL products in the proposed liner system are internally reinforced with needle-punched fibers to ensure that the shear resistance of the internal (Bentonite) layer also exceeds the stability requirement. Improvement in stability is expected since the interface shear resistance of HDPE/GCL in the proposed liner system is superior than the interface shear resistance of HDPE/CCL in the permitted liner system.	Attachment A, Equivalency Demonstration and References
4/13/2018	a.The 2011 report identified seemingly satisfactory sliding (or translational) factors of safety under various conditions, but made no mention of rotational factors of safety, including possibly failure surfaces that could intersect well into the underlying landfill and natural soil layer. Were rotational failure envelopes part of the analysis? What were the resulting factors of safety for various conditions?	Rotational failure envelops were actually examined in the 2011 permit submittal. Both rotational (aka, "circular") and sliding (aka, "non-circular") slipping planes were part of the 2011 analyses. Ranges of FS-value were 1.5-2.4 (for pre-filling condition); 1.5-1.6 (for partial filling condition); and 1.5-2.0 (for post-filling condition).	"Volume III – WDI Operating License Application, Master Cells VI F & G, Basis of Design Report", NTH Consultants, submitted February 2011, revised September 2011
4/13/2018	How will the design ensure that no new leachate from the expansion make it to the unlined waste cell beneath the expansion?	The approved 2011 design incorporates a "complete encapsulation" of the expansion waste by incorporating (1) continuous transition of liner systems between adjacent sub-cells and (2) tie-in of the final cover geomembrane to the expansion waste primary base liner geomembrane. Leachate from the expansion waste will be separated from the underlying (unlined) waste.	Attachment B, Permit Engineering Drawings
4/13/2018	What is the anticipated settlement of the underlying landfill after the expansion?	According to the 2011 expansion submittal, approved by the EPA and MDEQ, the total settlement of the MC VI-F & G cell floor ranges from 2.5 feet to 17 feet under maximum expansion waste loading. The current proposed design changes will not alter these calculations.	N/A
4/13/2018	How will the anticipated differential and global settlement of the preregulatory landfill challenge the expansion liner? i. Have the biaxial properties of geogrid and GCL been evaluated for those conditions?	The estimated settlement will not adversely impact the proposed liner system. GCL is well known for its superior capability to endure settlement induced tensioning. Dr. Qian of the MDEQ stated in his book ["Geotechnical aspects of landfill design and construction". New Jersey: Prentice Hall Inc. (2001)] that a compacted clay liner can only tolerate settlement induced strain of 0.1 to 4% whereas geocomposite clay liner can tolerate 5 - 16% strain. There are no proposed changes to the geogrid already approved by the EPA and MDEQ.	N/A
4/13/2018	What is the anticipated of differential and global settlement on the slope and performance of the leachate collection system?	As concluded in the approved 2011 permit submittal, the post settlement slopes are greater than 2.24 percent on the cell floor and greater than 1.0 percent along the leachate collection pipe locations – both satisfying the regulatory requirements and demonstrating satisfactory performance of the leachate collection system. Nevertheless, as indicated in the response above, GCLs are superior than CCLs in resisting any settlement induced tensioning.	N/A

Question Date	Question From MDEQ/U.S. EPA Region 5	Answer from Wayne Disposal, Inc./CTI and Associates, Inc.	Corresponding information in the 2018 Permit Modification Request
4/13/2018	GCLs can be subject to rapid changes in hydraulic properties when exposed to specific leachate constituents like calcium. Have the GCLs been evaluated for chemical resistance to the anticipated waste leachates? What method was used and what was the result?	Yes the GCLs had been conservatively evaluated by the manufacture's R&D laboratory for chemical resistance (compatibility) of the primary GCL (Resistex 200^{TM}) against leachate samples supplied by WDI. After 100 hours of permeation , the lab has measured a permeability of 1.0×10^{-9} cm/sec with 0.35 pore volumes of leachate passing through the specimen. This means that the bentonite polymer blend in the Resistex® 200 FLW9 GCL is hydrating and cutting off flow. The GCL manufacture, based on the preliminary test results, recommend a conservative "upper bound" estimate for permeability as 5×10^{-9} cm/sec to be used for techcnial purposes. With additional time and data collected from the site specific testing, the permeability value is expected to decrease further. For the demonstrative calculations, a conservative permeability of 1×10^{-8} cm/sec was used in the flux demonstration. In other words, an extra adjustment factor of 2.0 was applied for additional conservatism.	2018 Permit Modification Letter Report section titled "Equivalency Demonstration"
4/13/2018	GCLs can be subject to thinning under strain and wetting. How will this be prevented?	Thinning of GCLs can be prevented by maintaining adequate thickness (min. 1 ft) of cover soil between the equipment tires/tracks and the GCL at all times during the installation process. This important requirement will be included in the CQA plan and will be strictly enforced via full-time CQA observation/verification during construction of the proposed liner system.	2018 Permit Modification Letter Report Attachment C, GCL Manufacturer Specifications, CQA Manual, and Installation Guidelines.
4/13/2018	The design recognizes that subgrade preparation will be essential, yet 1 inch diameter stones are allowable before the proof rolling (final prep) of the surface. Once assembled, those stones may contribute to localized thinning of the GCL clay. Have designers considered a smaller allowable stone size AND considered a specification pertaining to angularity of the stones, which also affect thinning and/or puncture of the GCL material?	Based on the industry standard and past experiences, stone particle protrusion can be effectively eliminated by limiting the maximum-allowed stone size to 1" in the upper most lift of the attenuation layer and requiring proof-rolling of the prepared subgrade before GCL deployment. All subgrade preparation requirements will be listed in the CQA Plan and technical specifications. The Certifying Engineer's approval of the subgrade will be obtained prior to GCL installation.	2018 Permit Modification Letter Report section titled "Proposed Liner System"
4/13/2018	How will the GCLs be protected after installation? The bearing capacity slide of March 28 indicates 1 ft of soil atop the GCL at all times, is this sufficient for construction vehicles?	Industry standard and past experiences have demonstrated that an adequate thickness of cover soil (minimum 12") will prevent damage of GCLs due to construction equipment loading. Specifications of allowable construction vehicles will be listed in the CQA plan or on the drawings issued for construction.	2018 Permit Modification Letter Report section titled "Proposed Liner System"
4/13/2018	What is the estimated Impact of the overburden on leachate generation from the cell underlying the expansion?	Leachate generation will be reduced due to cutting off infiltration through the existing cell's clay cap by the installation of the new double composite liner. Although not required by rule, WDI will continue to remove leachate from the underlying cell.	N/A
4/13/2018	Is there a plan to circulate leachate on the expansion?	No. There is no plan to recirculate leachate on the expansion.	N/A

Proposed Permit Modification - Upgrades to MC VI-G Phase 2 Liner Design
Wayne Disposal, Inc., Belleville, Wayne County, Michigan

Response to MDEQ's May 03, 2018 Comments

1. CTI needs to consider increasing both the width and depth of the anchor trench shown in West Perimeter Dike 4 on revised Drawing No. 22A. It seems to be impossible to bend and bury total 9 to 10 layers of geosynthetic materials (including four layers of GCL, two layers of 80-mil geomembrane, two layers of geocomposite, and one or two layers of geogrid) into a 2'x´ 2' standard anchor trench.

   Response:

   The size of the anchor trench is increased to 3 ft x 3 ft as now shown on Detail 4 of Drawing No. 22A, included in Attachment B of the Permit Modification Letter Report.

2. The geocomposite used as the primary leachate drainage layer in MC VI-G Phase 2 (Subcell G3) shown in MC VI Phase 2 (Subcell 6E) to MC VI-G Phase 2 (Subcell G3) Tie-In Detail 1 on the revised Drawing No. 22B should be extended to overlap the existing primary leachate drainage geocomposite layer in MC VI Phase 2 (Subcell 6E) and the geonet cores should be joined by ties with plastic fasteners and the top geotextiles should be sewed together. The geocomposite used as the leak detection layer should also do this.

   Response:

   The detail is revised. The requirements for geocomposite connection are added in Detail 3 on Sheet 22A, included in Attachment B of the Permit Modification Letter Report. Detail 3 on Sheet 22A was referenced to all tie-in connections.

3. The overlapped connections of the geocomposite layers used as the primary leachate drainage layer and the leak detection layer shown in in MC VI-G Phase 1 and MC VI-G Phase 2 Tie-In Detail 2 on revised Drawing No. 22B should be revised. The geocomposite used as the primary leachate drainage layer in MC VI-G Phase 2 (Subcells G2 and G3) shown in MC VI-G Phase 1 and MC VI-G Phase 2 Tie-In Detail 2 on revised Drawing No. 22B should be extended to cover the existing primary leachate drainage geocomposite layer and the geonet cores should be joined by ties with plastic fasteners and the top geotextiles should be sewed together. The geocomposite used as the leak detection layer should also do this. Just like the shingles and tiles on the roof, the shingles on the upper part of the slope should always cover the shingles on the lower part of the slope.

Response:

The detail is revised. The requirements for geocomposite connection are added in Detail 3 on Drawing No. 22A, included in Attachment B of the Permit Modification Letter Report. Detail 3 on Sheet 22A was referenced to all tie-in connections including those on Drawing No. 22B.

Proposed Permit Modification - Upgrades to MC VI-G Phase 2 Liner Design
Wayne Disposal, Inc., Belleville, Wayne County, Michigan

Response to MDEQ's May 09, 2018 Comments

Attachment A: Equivalency Information and References

1. Two shear resistance requirements obtained from the slope stability analysis shown Page 10/13 should not only include the interfaces between geosynthetic-to-geosynthetic or geosynthetic-to-soil, but also include internal shear strengths for different GCLs.

    Response:

    Agree. The following paragraph will replace the current language on Page 10 of 13 of the Equivalency Information and References (Attachment A).

    "WDI will, as part of the CQA requirements, conduct direct shear tests (ASTM D6243) for relevant GCL-related interfaces (e.g., against 80-mil textured HDPE geomembranes, between different GCL products, against cohesive attenuation layer soils, etc.) as well as internal shear strength for different GCL products before approving the products to be used for construction of the MC VI-G Phase 2 liner system."

Appendix A-2: Maximum Head-on-Liner Calculation

2. It is indicated in Design Criteria/Design Basis (with Reference to Source of Data) in Page 1 of 2 that "1. Average daily peak leachate generation rates were obtained from "Leachate Generation Estimation and Head Calculation" (NTH, 2011), which are 8,960 gal/acre/day for Subcell G2 and 7,874 gal/acre/day for Subcell G3. This part of the calculation process and calculation results conducted by NTH should be attached in Appendix A-2 for checking by the reviewers.

    Response:

    The calculation sheets and related attachments for Leachate Generation Estimation and Head Calculation (NTH, 2011) are included in this response package as Appendix A-2.4.

3. It is only indicated in Design Criteria/Design Basis (with Reference to Source of Data) in Page 1 of 2 that the maximum drainage length of Subcells G2 and G3 is 200 ft and floor slopes are 5.6% and 5.8%, respectively. But, the maximum slope lengths of the 3:1 sideslope in Subcells G2 and G3, which were used in the maximum leachate head calculation, were not indicated.

Response:

A new figure on page 1 of Appendix A-2.2, indicating the location of the maximum drainage length on the side slope, is included in the revised calculation sheet.

4. The same inflow rate of 8,960 gal/acre/day was used to calculate the maximum leachate head on the liner for Subcell G2 floor and 3(H):1(V) sideslope. If the inflow rate was calculated by using HELP model, the inflow rate results should be different for the flat subbase and 3(H):1(V) sideslope. It is the same for Subcell G3 floor and 3(H):1(V) sideslope.

Response:

A single leachate generation rate for each cell was reported in the current permit application report (approved by the MDEQ on May 4, 2012 and EPA on September 27, 2013). The generation rates of 8,960 and 7,874 gal/acre/day were estimated for Subcells G2 and G3, respectively. According to CTI's past design experiences, these leachate generation rates for sideslopes are significantly higher than any other landfill in Michigan. It is also CTI's understanding that steeper (e.g., 3H:1V) sideslope inclination tends to result in higher drainage capacity and the maximum head-on-liner will likely occur near the toe of the slope.

To verify this understanding, CTI repeated the head-on-liner calculation using a "doubled" leachate generation rate. As shown in the attached calculation sheet, the calculated maximum head-on-liner value remains unchanged. Please also note that the higher performance Resistex® 200 GCL used on the cell floor will be extended 5-ft vertically up the side slope. The estimated maximum leachate head on the sideslope will actually occur within this "enhanced" section.

5. In Head on Liner Calculation for Subcell G2 – Side Slope, it was obtained that the maximum head on liner (McEnroe numerical) in all slope is equal to 5.18 inches. However, the result listed in the box indicate that the maximum head on liner (McEnroe 93 with free drain) is only 0.9982 inches. It is the same for Subcell G3 – Side Slope. CTI must clarify this discrepancy.

Response:

Since the "free draining" condition will not be met for the sideslope cases, the results from the McEnroe 96 equation (for free draining condition) are not valid in this calculation. The value was included on the spreadsheet for comparison purposes only. All irrelevant results have been removed from the spreadsheet to avoid confusion.

6. "The maximum head on liner (McEnroe 93 with free drain + Superposition)" is listed in the box in Head on Liner Calculations. What is this meaning and what is "Superposition"?

Response:

“Superposition” in this case is an approach which estimates the head-on-liner by adding the depth of leachate at the discharge point (i.e., leachate collection pipe) to the maximum head-on-liner determined using the McEnroe Equitation under a free draining condition). All irrelevant results have been removed from the spreadsheet to avoid confusion. Results from the numerical solution, which are relevant to this calculation, remain.

7. CTI should give a description to explain how two equations used for Slope 1 and Slopes 2 – 5 were derived from McEnroe 1993’s paper. Is it not continuous to connect these five segments of the curves, i.e., it should be a continuous phreatic surface of the leachate flow?

Response:

The derivation of the equations and verification of the results using numerical solution are documented in a CTI internal report, which is attached with this response package. The phreatic surface is continuous however the shape of the curve at each segment may vary.

8. In Head on Liner Calculations, the thicknesses of sand used in the calculations were 3.0, 3.0, 3.0, 3.0, and 2.0 inches for Slopes 5, 4, 3, 2, and 1 at Subcell G2 – Floor; 2.0, 2.0, 2.0, 2.0, and 2.0 at Subcell G3 – Floor; 6.0, 6.0, 6.0, 6.0, and 6.0 at Subcells G2 and G3 – Side Slope. Do these thicknesses represent the saturated depth of the 12-inch protective sand placed on the geocomposite drainage layer? Was the combined (apparent) permeability calculated from the combination of the permeabilities of the thickness of the geocomposite and the saturated depth of the sand layer? If so, the leachate flow in the geocomposite and protective sand layer is in a unconfining flow condition. If the leachate depth is greater than the thickness of the geocomposite, the saturated depth in the protective sand layer is unknown. It will change with the phreatic surface. The true saturated depth in the sand layer can be calculated by using trial and error method. Using a fixed saturated sand depth will affect the correctness of the calculated maximum leachate head results.

Response:

An assumed saturated thickness of the sand layer is used to determine the combined hydraulic conductivity of the saturated drainage layer per the approach presented by Qian et al. 2004 (Qian, X.D., Gray, D.H., and Koerner, R.M. (2004), “Estimation of Maximum Liquid Head over Landfill Barriers,” Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 130:5, 488-497).

$$k_{combined} = k_{geonet} + \left(k_{sand} - k_{geonet}\right)\frac{t_{sand}{}^{2}}{\left(t_{sand} + t_{geonet}\right)^{2}}$$

One of the ways to estimate the thickness of the saturated sand layer is using the trial-and-error method. However, even with the trial-and-error method, thickness of the saturated sand layer is not a “true” depth of leachate in the layer since the saturated thicknesses vary within each segment. To simplify the calculation and provide a conservative result (higher head on liner), an assumed saturated thickness, which is greater than the maximum head-on-liner in the same segment was utilized in the calculation.

9. CTI should explain why the thickness of geonet was assumed to be 0 for Slope 5 at Subcells G2 and G3 – Side Slope and the thickness of sand was still 6.0 inches.

Response:

The thickness of the geonet is not zero in “Slope 5”. The thickness of the geonet is zero in “Slope 1” which was not used in the calculation. Note that the flow length was also set to zero for “Slope 1” in both spreadsheets.

Material and Construction Specifications and CQA Program

10. The geosynthetic-to-geosynthetic interface, geosynthetic-to-soil interface and GCL internal friction requirements obtained from slope stability analysis must be added in the CQA program document beyond GCL CQA program and the material and construction specifications shown in the Drawings.

Response:

Agree. All interface- and internal-shear resistance testing associated with various GCL products, including standard methods, procedures and minimum requirements will be included both in the technical specifications and on the construction drawings as part of the CQA program.

11. The material specifications of 5-ft cohesive soil used as an attenuation layer placed beneath the two layers of GCL primary liner, such as particle gradation or CL, LL and PI, dry density requirement for compaction, must be also included in the CQA program document and shown in the Drawings.

Response:

Agree. Soil properties such as Atterberg limits (ASTM D4318) and grain size distribution (ASTM D422) will be tested to confirm that the proposed material meets the classification requirements (SC, CH, CL, CL/ML or ML per the Unified Soil Classification System - ASTM D2487). Modified Proctor moisture-density correlation (ASTM D1557) will also be tested to determine the maximum dry density of the tested soil. Field testing will be performed to verify the in-place density of the attenuation soil meets the minimum 90% requirement.

Proposed Permit Modification - Upgrades to MC VI-G Phase 2 Liner Design
Wayne Disposal, Inc., Belleville, Wayne County, Michigan

Response to EPA's May 14, 2018 Comments

1. Will a Construction Quality Assurance (CQA) program document be submitted?

   Response:

   Other than the GCL Section, which will be superseded by the CQA documents included in Attachment D of the submitted Permit Modification Letter Report ("GCL Manufacturer Specifications, CQA Manual, and Installation Guidelines"), the current CQA Plan (approved by the MDEQ on May 4, 2012 and EPA on September 27, 2013) will remain as the official CQA program document for the construction of Master Cell VI-F & G.

   a. CQA must address the Geomembrane/Geocomposite interface with regards to slope stability.

      Response:

      The following paragraphs on Page 10 of 13 of the "Equivalency Information and References" (Attachment A of the submitted Permit Modification Letter Report) should properly address all interface- and internal shear resistance issues associated with slope stability.

      - *As long as the interim waste slope during filling does not exceed an inclination of 3.5(H) to 1(V), a friction angle of 13.8 degrees or higher between any different geosynthetic-to-geosynthetic or geosynthetic-to-soil interfaces will result in satisfactory factor of safety (FS) values of 1.5 or greater.*

      - *As long as a combination of friction and adhesion under an overburden pressure of 1.0 psi is greater than a friction angle of 21.8 degrees, stability of liner systems on slopes not steeper than 3(H) to 1(V) can be ensured.*

      WDI will, as part of the CQA requirements, conduct direct shear tests (ASTM D6243) for relevant GCL-related interfaces (e.g., against 80-mil textured HDPE geomembranes, between different GCL products, against cohesive attenuation layer soils, etc.) as well as internal shear strength for different geosynthetic products before approving the products to be used for construction of the MC VI-G Phase 2 liner system."

b. CQA must address the rolling and prepping of soil upon which the GCL lies.

   Response:

   As indicated on Page 11 of 13 of the "Equivalency Information and References" (Attachment A of the submitted Permit Modification Letter Report), technical specifications for the GCL (included in Attachment D of the submitted Permit Modification Letter Report) limit any stone particle in the upper most lift of the subgrade soils (i.e., the attenuation layer and the structural fill) to be not larger than 1 inch (25 mm) in size. Proof-rolling of the prepared subgrade surface is also required to reduce stone particle protrusion.

c. CQA must address the weights of vehicles allowed after installation of GCL.

   Response:

   As indicated on Page 17 of 25 of CETCO GCL CQA Manual (Attachment D of the submitted Permit Modification Letter Report entitled "GCL Manufacturer Specifications, CQA Manual, and Installation Guidelines") no heavy equipment should come in direct contact with the GCL. In some cases, however, it is necessary to drive equipment directly on the GCL. Permission to do so will be granted by CETCO through the CQA engineer on a case-by-case basis only and will include restrictions on low-pressure, rubber-tired equipment only.

   Additionally, as indicated on Page 10 of 13 of the "Equivalency Information and References" (Attachment A of the submitted Permit Modification Letter Report), a minimum thickness of 1 foot (300 mm) of cover soil is specified as a technical requirement and CQA site personnel will observe/verify/document that such a requirement is maintained between the equipment tires/tracks and the GCL at all times during the installation process.

2. Anticipated settlement of underlying landfill after expansion is 3-17 feet. Did designer consider increasing overlap of the GCL materials to allow for this deformation to prevent overlapped GCL panels from separating and opening flow paths during settlement?

   Response:

   As indicated in the CETCO GCL CQA Manual (Attachment D of the Permit Modification Letter Report entitled "GCL Manufacturer Specifications, CQA Manual, and Installation Guidelines"), the minimum acceptable overlap between GCL panels is 6 inches (150 mm). This overlap distance is considered as industry standard for over 2 decades and has been commonly used in numerous applications – including many landfill overfill liner (aka "piggybacking") and final closure systems.

   To name a few, the following commercial and municipal MSW landfills all have incorporated GCL in their permitted piggybacking liner or final closure systems using the same overlapping distance:

- Eagle Valley Security Landfill – Orion Charter Township, Michigan
- Westside Security Landfill – Three Rivers, Michigan
- Pine Tree Acres Landfill - Lenox, Michigan
- Northern Oaks Security Landfill – Harrison, Michigan
- Woodland Meadows Security Landfill – Van Buren Township, Michigan
- Smiths Creek Landfill – Smiths Creek, Michigan
- City of Midland Landfill – Midland, Michigan
- Wexford County Landfill – Manton, Michigan

It is important to recognize that final closure systems (of landfills, surface impoundments, etc.), compared with the proposed cell liner application, provide much less "confining" overburden pressure. Higher overburden pressure, and consequently greater shear resistance, keeps the overlapped GCL seams from separating when experiencing uneven settlement.

WDI believes that the proposed overlapping distance, with much greater confining overburden pressure provided by the proposed cell liner application, will adequately prevent the separation of GCL panels. However, WDI will request "offsetting" the overlapping area between the upper and lower GCL layers to provide additional redundancy and maximize the protection. This additional installation and CQA requirements will be incorporated in the construction drawings of Subcells G2 and G3.

3. What damage might occur to the leachate collection system during settlement of the underlying landfill?

Response:

As concluded in the approved 2011 permit submittal, the "post settlement" slopes are greater than 2.24 percent on the cell floor and greater than 1.0 percent along the leachate collection pipe locations – both satisfying the regulatory requirements and demonstrating satisfactory performance of the leachate collection system.

4. The buffer layer for the GCL does not address the angularity of stone. Has this been addressed?

Response:

As indicated on Page 11 of 13 of the "Equivalency Information and References" (Attachment A of the submitted Permit Modification Letter Report), maximum stone size in the upper most lift of the subgrade soils (i.e., the attenuation layer underneath the primary liner and the structural fill layer underneath the secondary liner) will be limited to not larger than 1 inch (25 mm). Any stone particles that are greater than 1' in size, or more angular than “sub-rounded” in shape will be handpicked and the remaining cavity will be backfilled with clay.

Moreover, proof-rolling of the subgrade surface is also required before the deployment of GCL. This procedure is intended to create a “smooth” subsurface and further reduce the chance of any significant stone particle protrusion.

Combining with the superb “self-healing” characteristic inherent to bentonite, it is believed that the above CQA requirements are sufficient and adequate to address potential concerns associated with substrate stone angularity and ensure a superb liner performance.

Attachment D: GCL Manufacturer Specifications, CQA Manual, and Installation Guidelines

TECHNICAL REFERENCE

RESISTEX® 200 FLW9 CERTIFIED PROPERTIES

CETCO® Resistex® geosynthetic clay liners are engineered to provide the highest level of chemical compatibility in extremely aggressive leachate environments such as some coal combustion product storage facilities, mining operations, and industrial waste storage facilities. Site-specific compatibility testing is strongly recommended.[7]

MATERIAL PROPERTY	TEST METHOD	TEST FREQUENCY	CERTIFIED VALUES
Scrim-reinforced Nonwoven Base Geotextile Mass/Area[1]	ASTM D5261	200,000 ft^2 (20,000 m^2)	6.0 oz/yd^2 (200 g/m^2) min.
Nonwoven Cap Geotextile Mass/Area[1]	ASTM D5261	200,000 ft^2 (20,000 m^2)	9.0 oz/yd^2 (300 g/m^2) min.
Bentonite Moisture Content[2]	ASTM D2216	1 per 50 tonnes	12% max.
Bentonite Swell Index[2]	ASTM D5890	1 per 50 tonnes	24 mL/2g min.
Bentonite Fluid Loss[2]	ASTM D5891	1 per 50 tonnes	18 mL max.
Bentonite Mass/Area[3]	ASTM D5993	40,000 ft^2 (4,000 m^2)	0.75 lb/ft^2 (3.7 kg/m^2) min.
Total Mass/Area[3]	ASTM D5993	40,000 ft^2 (4,000 m^2)	0.85 lb/ft^2 (4.2 kg/m^2) min.
GCL Moisture Content	ASTM D5993	40,000 ft^2 (4,000 m^2)	35% max.
GCL Grab Strength[4]	ASTM D6768	200,000 ft^2 (20,000 m^2)	50 lbs/in (8.8 kN/m) min.
GCL Peel Strength	ASTM D6496	40,000 ft^2 (4,000 m^2)	3.5 lbs/in (610 N/m) min.
GCL Hydraulic Conductivity[5]	ASTM D5887	250,000 ft^2 (25,000 m^2)	3 x 10^{-11} m/s max.
GCL Hydrated Internal Shear Strength[6]	ASTM D6243	1,000,000 ft^2 (100,000 m^2)	500 psf (24 kPa) typ.@ 200 psf (9.6 kPa)

Notes:

[1] Geotextile property tests performed on the geotextile components before they are incorporated into the finished GCL product.

[2] Bentonite property tests performed before the bentonite is incorporated into the finished GCL product.

[3] Reported at 0 percent moisture content.

[4] All tensile strength testing is performed in the machine direction using ASTM D6768.

[5] Index flux and hydraulic conductivity testing with deaired distilled/deionized water at 80 psi (550 kPa) cell pressure, 77 psi (530 kPa) headwater pressure and 75 psi (515 kPa) tailwater pressure.

[6] Peak values measured at 200 psf (9.6 kPa) normal stress for a specimen hydrated for 48 hours. Site-specific materials, GCL products, and test conditions must be used to verify internal and interface strength of the proposed design.

MINERALS TECHNOLOGIES CETCO®

TECHNICAL REFERENCE

BENTOMAT® CL CERTIFIED PROPERTIES

CETCO® Bentomat® CL is a reinforced geosynthetic clay liner (GCL) consisting of a layer of sodium bentonite between a polypropylene woven geotextile and a polypropylene nonwoven geotextile, which are needle-punched together and laminated to a polyethylene geofilm.

MATERIAL PROPERTY	TEST METHOD	TEST FREQUENCY	CERTIFIED VALUES
Bentonite Moisture Content[2]	ASTM D2216	1 per 50 tonnes	12% max.
Bentonite Swell Index[2]	ASTM D5890	1 per 50 tonnes	24 mL/2g min.
Bentonite Fluid Loss[2]	ASTM D5891	1 per 50 tonnes	18 mL max.
Bentonite Mass/Area[3]	ASTM D5993	40,000 ft^2 (4,000 m^2)	0.75 lb/ft^2 (3.7 kg/m^2) min.
Geofilm Density[1]	ASTM D1505	200,000 ft^2 (20,000 m^2)	0.92 g/cm^3
Geofilm Thickness[1]	ASTM D5199	200,000 ft^2 (20,000 m^2)	5 mil (0.12 mm) min.
Geofilm Break Strength[1,4]	ASTM D882	200,000 ft^2 (20,000 m^2)	14 lbs/in (2.5 kN/m) min.
Total Mass/Area[3]	ASTM D5993	40,000 ft^2 (4,000 m^2)	0.84 lb/ft^2 (4.1 kg/m^2) min.
GCL Moisture Content	ASTM D5993	40,000 ft^2 (4,000 m^2)	35% max.
GCL Grab Strength[5]	ASTM D6768	200,000 ft^2 (20,000 m^2)	30 lbs/in (5.3 kN/m) min.
GCL Peel Strength	ASTM D6496	40,000 ft^2 (4,000 m^2)	3.5 lbs/in (610 N/m) min.
GCL Hydraulic Conductivity[6]	ASTM D5887	250,000 ft^2 (25,000 m^2)	5 x 10^{-12} m/s max.
GCL Index Flux[6]	ASTM D5887	250,000 ft^2 (25,000 m^2)	1 x 10^{-9} m^3/m^2/s max.
GCL Hydrated Internal Shear Strength[7]	ASTM D6243	1,000,000 ft^2 (100,000 m^2)	500 psf (24 kPa) typ.@ 200 psf (9.6 kPa)

Notes:

[1] Geosynthetic property tests performed on the geosynthetic components before they are incorporated into the finished GCL product.

[2] Bentonite property tests performed before the bentonite is incorporated into the finished GCL product.

[3] Reported at 0 percent moisture content.

[4] Geofilm tensile break strength performed in the machine and cross-machine directions using ASTM D882.

[5] GCL tensile strength testing is performed in the machine direction using ASTM D6768.

[6] ASTM D5887 is modified to include the laminated thin flexible membrane on the test specimen. Index flux and hydraulic conductivity testing with deaired distilled/deionized water at 80 psi (550 kPa) cell pressure, 77 psi (530 kPa) headwater pressure and 75 psi (515 kPa) tailwater pressure. ASTM D5887 (modified) testing is performed only on a periodic basis because the thin flexible membrane is essentially impermeable. The Bentomat® GCL core (without the flexible membrane) has a maximum hydraulic conductivity of 5 x 10^{-11} m/s with deaired distilled/deionized water. For more information, see CETCO® Technical Reference (TR) Nos. 111 and 112.

[7] Peak values measured at 200 psf (9.6 kPa) normal stress for a specimen hydrated for 48 hours. Site-specific materials, GCL products, and test conditions must be used to verify internal and interface strength of the proposed design.

MINERALS TECHNOLOGIES® CETCO®

TECHNICAL REFERENCE

BENTOMAT® DN
CERTIFIED PROPERTIES

CETCO® Bentomat® DN is a reinforced geosynthetic clay liner (GCL) consisting of a layer of sodium bentonite between two polypropylene nonwoven geotextiles, which are needle-punched together.

MATERIAL PROPERTY	TEST METHOD	TEST FREQUENCY	CERTIFIED VALUES
Bentonite Moisture Content[1]	ASTM D2216	1 per 50 tonnes	12% max.
Bentonite Swell Index[1]	ASTM D5890	1 per 50 tonnes	24 mL/2g min.
Bentonite Fluid Loss[1]	ASTM D5891	1 per 50 tonnes	18 mL max.
Bentonite Mass/Area[2]	ASTM D5993	40,000 ft^2 (4,000 m^2)	0.75 lb/ft^2 (3.7 kg/m^2) min.
Total Mass/Area[2]	ASTM D5993	40,000 ft^2 (4,000 m^2)	0.83 lb/ft^2 (4.1 kg/m^2) min.
GCL Moisture Content	ASTM D5993	40,000 ft^2 (4,000 m^2)	35% max.
GCL Grab Strength[3]	ASTM D6768	200,000 ft^2 (20,000 m^2)	50 lbs/in (8.8 kN/m) min.
GCL Peel Strength	ASTM D6496	40,000 ft^2 (4,000 m^2)	3.5 lbs/in (610 N/m) min.
GCL Hydraulic Conductivity[4]	ASTM D5887	250,000 ft^2 (25,000 m^2)	5 x 10^{-11} m/s max.
GCL Index Flux[4]	ASTM D5887	250,000 ft^2 (25,000 m^2)	1 x 10^{-8} $m^3/m^2/s$ max.
GCL Hydrated Internal Shear Strength[5]	ASTM D6243	1,000,000 ft^2 (100,000 m^2)	500 psf (24 kPa) typ.@ 200 psf (9.6 kPa)

Notes:

[1] Bentonite property tests performed before the bentonite is incorporated into the finished GCL product.

[2] Reported at 0 percent moisture content.

[3] All tensile strength testing is performed in the machine direction using ASTM D6768.

[4] Index flux and hydraulic conductivity testing with deaired distilled/deionized water at 80 psi (550 kPa) cell pressure, 77 psi (530 kPa) headwater pressure and 75 psi (515 kPa) tailwater pressure.

[5] Peak values measured at 200 psf (9.6 kPa) normal stress for a specimen hydrated for 48 hours. Site-specific materials, GCL products, and test conditions must be used to verify internal and interface strength of the proposed design.

TR 401-BDN-3.5lb/in- D5889/GRI-GCL3
02/2017

MINERALS TECHNOLOGIES ® CETCO®

TECHNICAL REFERENCE

BENTOMAT® ST CERTIFIED PROPERTIES

CETCO® Bentomat® ST is a reinforced geosynthetic clay liner (GCL) consisting of a layer of sodium bentonite between a polypropylene woven geotextile and a polypropylene nonwoven geotextile, which are needle-punched together.

MATERIAL PROPERTY	TEST METHOD	TEST FREQUENCY	CERTIFIED VALUES
Bentonite Moisture Content[1]	ASTM D2216	1 per 50 tonnes	12% max.
Bentonite Swell Index[1]	ASTM D5890	1 per 50 tonnes	24 mL/2g min.
Bentonite Fluid Loss[1]	ASTM D5891	1 per 50 tonnes	18 mL max.
Bentonite Mass/Area[2]	ASTM D5993	40,000 ft^2 (4,000 m^2)	0.75 lb/ft^2 (3.7 kg/m^2) min.
Total Mass/Area[2]	ASTM D5993	40,000 ft^2 (4,000 m^2)	0.81 lb/ft^2 (4.0 kg/m^2) min.
GCL Moisture Content	ASTM D5993	40,000 ft^2 (4,000 m^2)	35% max.
GCL Grab Strength[3]	ASTM D6768	200,000 ft^2 (20,000 m^2)	30 lbs/in (5.3 kN/m) min.
GCL Peel Strength	ASTM D6496	40,000 ft^2 (4,000 m^2)	3.5 lbs/in (610 N/m) min.
GCL Hydraulic Conductivity[4]	ASTM D5887	250,000 ft^2 (25,000 m^2)	5 x 10^{-11} m/s max.
GCL Index Flux[4]	ASTM D5887	250,000 ft^2 (25,000 m^2)	1 x 10^{-8} m^3/m^2/s max.
GCL Hydrated Internal Shear Strength[5]	ASTM D6243	1,000,000 ft^2 (100,000 m^2)	500 psf (24 kPa) typ.@ 200 psf (9.6 kPa)

Notes:

[1] Bentonite property tests performed before the bentonite is incorporated into the finished GCL product.

[2] Reported at 0 percent moisture content.

[3] All tensile strength testing is performed in the machine direction using ASTM D6768.

[4] Index flux and hydraulic conductivity testing with deaired distilled/deionized water at 80 psi (550 kPa) cell pressure, 77 psi (530 kPa) headwater pressure and 75 psi (515 kPa) tailwater pressure.

[5] Peak values measured at 200 psf (9.6 kPa) normal stress for a specimen hydrated for 48 hours. Site-specific materials, GCL products, and test conditions must be used to verify internal and interface strength of the proposed design.

CETCO GCL

CONSTRUCTION QUALITY ASSURANCE (CQA) MANUAL

Version 6.0, August 2008

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APPENDIX B GCL Construction Quality Assurance Checklist

SECTION 1
INTRODUCTION

1.1 Definitions

Construction Quality Assurance. For the purposes of this manual, construction quality assurance (CQA) is defined as a planned system of activities that provides assurance that *installation* of the geosynthetic clay liner (GCL) proceeds in accordance with the project design drawings and specifications. In general, these activities include continuous inspection of the installation, testing of materials and procedures, and overall documentation.

Construction Quality Control. Again, for the purposes of this manual, construction quality control (CQC) is defined as a planned system of activities that provides assurance that the properties of the GCL *materials* meet the requirements of the project specifications. These activities primarily include materials testing and documentation.

There is a great deal of overlap in the nature of CQA and CQC, and from a practical standpoint, CQA and CQC activities are often performed by the same party. For this reason, we will use the term CQA to describe *all* of the quality-oriented tasks relating to the GCL and its installation.

1.2 Scope and Purpose of the CQA Manual

This manual is written to address third-party CQA activities and is *not* intended as a guide for GCL installation. Installation guidelines are available separately from CETCO (see Technical References TR-402). This manual is also not intended to describe the various *manufacturing* quality assurance and quality control (MQA/MQC) activities performed by CETCO at the GCL manufacturing facilities (see Technical Reference No. TR-403).

The purpose of the CQA Manual is provide the project CQA personnel with a general format for assuring that the GCL delivered to the job meets the requirements of the specifications and that this material is installed in accordance with the design drawings and specifications. This manual should be modified as necessary by the design or CQA engineer in order to account for site-specific or project-specific concerns and conditions. Any such changes, however, should be discussed with CETCO before they are introduced into the final version of the project CQA plan.

For the convenience of the CQA personnel, an overall CQA Checklist is provided in Appendix A. This checklist or a similar version thereof is designed to be used on a daily basis to document that all CQA activities are consistently executed throughout the project. The checklists should be maintained at the job site and should be included chronologically in the final CQA documentation package (Section 7).

SECTION 2
PERSONNEL QUALIFICATIONS AND RESPONSIBILITIES

It is vital that all parties involved in the installation of the GCL are in close communication with each other throughout the project, and that they fully understand the requirements of the project CQA plan. For the purposes of this manual, the qualifications and responsibilities of the various parties are delineated as follows:

Installing Contractor

Responsible for installing the GCL. The contractor should appoint an on-site Construction Supervisor to coordinate the installation effort and to interact with the other parties on the job site. The installing contractor should have prior experience in GCL installation and should staff the project with qualified technicians.

On-Site Engineer

Usually the design engineer or designee, this person is responsible for general oversight of the installation. Provides assurance that construction is performed as designed, although not formally responsible for CQA. Primary contact when the installing contractor is in need of clarification of design issues. Primary contact for dispute/problem resolution. This person should be a registered professional engineer.

CQA Engineer

Charged with CQA for Bentomat installation as well as for any other liner system components. Oversees all CQA inspection, testing, and documentation. This person should be a registered professional engineer or a certified geosynthetics installation technician. This person must also be independent of the other parties on site.

Manufacturer's Representative

CETCO may provide on-site start-up assistance, especially those in which the installer has little or no prior experience or where unusual site conditions exist. The on-site engineer or installer is responsible for notifying CETCO of the intended installation schedule such that CETCO may provide timely guidance during the start-up process. CETCO's GCL installation experience may provide valuable insights to the uninitiated engineer and/or installer.

CETCO also acts as the liaison between the manufacturing plant and the installer and coordinates the release of GCL from the plant in accordance with the installer's schedule. CETCO's *on-site* involvement is typically lessened when it is determined that the installer is sufficiently capable of installing GCL without CETCO's continuous assistance. CETCO remains available throughout the project should questions or problems arise.

CQA Laboratory

The GCL conformance tests in this manual are designed to be performed at the job site to facilitate real-time response as test results are generated. In some projects where additional testing is required, however, it may be necessary to utilize the services of an off-site laboratory. The on-site engineer should verify that the selected laboratory has ample experience in the testing of GCLs and is aware of the general content of the project CQA plan as well as its specific testing requirements. The CQA engineer should establish a key contact at the laboratory to coordinate sample delivery procedures, confirm testing parameters and methods, and arrange the timely reporting of test results.

It is recommended that a preconstruction meeting be held between the above parties in order to establish working relationships with one another and to review the design drawings and specifications prior to deployment of the GCL. Thereafter, regular meetings on a daily or weekly basis are recommended as the project continues.

SECTION 3
ON-SITE HANDLING

This section describes the procedures and equipment to be used in handling the GCL when it arrives at the job site. Proper execution of these procedures will ensure that the GCL is not damaged prior to installation. It should be noted that ASTM D 5888 also provides guidelines for GCL handling. The recommendations included herein are consistent with all ASTM guidelines.

CETCO's GCLs are produced in slightly different sizes depending upon the product selected. Weights and dimensions of these products and their corresponding core pipe sizes required for safe handling are provided in Table 1 below.

Product	Panel Size (m)	Roll Diam. (mm)	Typ. Roll Weight (kg)	Core Diam. (mm)	Core Pipe Diameter (mm)	Core Pipe Length (m)	Minimum Core Pipe Strength
Bentomat	4.57 x 45.7	610	1,200	100	89	6.1	XXH
Claymax	4.57 x 45.7	510	1,250	100	89	6.1	XXH

Table 1. GCL panel sizes and corresponding core pipe requirements.

It should be recognized that the weight of the GCL rolls will dictate what type of core pipe will be sufficiently strong for unloading and handling activities. Experience has shown that the type of steel from which the pipe was produced will influence its ability to sustain the weight of the roll. The strongest steel available should be used to prevent pipe bending. A core pipe that deflects more than 75 mm as measured from end to midpoint when the roll is lifted can cause damage to the GCL and is *not acceptable.* The pipes used to unload or deploy the GCL *must not bend* at any time.

3.1 Unloading Procedures

The GCL may be delivered to the job site in one of two ways: by flatbed truck or by closed trailer/container. Regardless of the delivery method, all unloading activities should take place away from main roadways and high-traffic areas at the site. The designated unloading area should be flat, dry, and stable, and should provide adequate peripheral access for the unloading equipment. Different techniques for unloading the GCL are used accordingly. Using the procedures and equipment described below will minimize unloading time.

3.1.1 Flatbed Truck Delivery

A front-end loader or backhoe is typically used to remove the rolls from the flatbed truck. Starting from the top rolls on the truck, the core pipe is inserted through the roll core. The core has an inside diameter of 100 mm but may be slightly bowed upon arrival to the job site. In this case, it may be necessary to assist the core pipe insertion process by using the back of the loader bucket to carefully push the pipe through the core.

After the core pipe has been inserted, straps or chains are looped around each end of the pipe protruding from the roll. The other ends of the chains should be connected to a spreader bar (typically an I-beam) of equal length to the core pipe. The spreader bar itself is suspended from the loader bucket. The purpose of the spreader bar is to prevent the chains from chafing the ends of the roll as it is lifted. It is recommended that the chains or straps be secured by the placing a pin through each end of the pipe. The GCL roll should then be lifted and slowly carried from the flatbed to the temporary storage area.

GCL rolls can also be provided with a pair of slings to facilitate lifting and handling.

3.1.2 Trailer or Container Delivery

The GCL may also be delivered in closed trailers or shipping containers. In these cases, different unloading equipment and techniques must be employed. Because of limited access to the GCL rolls, it is usually necessary to utilize an extendable-boom forklift with a "stinger" attachment. The forklift dealer or manufacturer can provide details on selecting the proper stinger for the type of forklift used at the job site.

The rolls are placed inside the trailer or container in the same way that they are positioned on a flatbed truck. The rolls are removed by inserting the stinger through the roll cores and lifting/pulling the rolls from the trailer/container.

3.2 Materials Handling

The equipment used to unload the GCL from the delivery vehicle may also be used to handle the material on site and to convey it to work areas. All unloading and handling activities must be undertaken with great care to avoid damage to the GCL. The GCL should never be handled in ways that could affect its performance. Some activities to avoid:

- Dropping the rolls from the edge of the delivery truck or container.
- Pushing or pulling the rolls on the ground surface.
- Lifting the roll without a core pipe.
- Bending the rolls by using a core pipe that cannot bear the weight of the roll.
- Forcing a bent core pipe through the core.
- Carrying the GCL over excessively rutted, bumpy terrain, causing the roll to bend and bounce in transit.

Adherence to these common-sense precautions will prevent handling-related damage to the Bentomat.

The CQA engineer or designee should supervise the unloading and storage operations. It is the duty of the CQA engineer to maintain records of the shipments and to verify that the roll numbers on the labels match the roll numbers on the bills of lading. Any apparent discrepancies should be noted and reported to CETCO.

At this time, all of the rolls should also be visually inspected for damage. Damaged rolls should be clearly marked and set aside where they will not be immediately used. Major damage suspected to have occurred during shipment should *immediately* be reported to the carrier and to CETCO (see Section 4.8.1).

3.3 On-Site Storage

The GCL may be stored at a project site indefinitely, provided that proper storage procedures are followed. First, a dedicated storage area should be identified. This area should be level, dry, well drained, and located away from high-traffic areas of the job site.

For reasons of safety and material integrity, GCL rolls must never be stored on end. Rolls should be stored horizontally, in small stacks not to exceed four rolls in height. It is preferred that the bottom rolls be placed on plywood, on an arrangement of pallets, or on some other man-made surface, to promote drainage and to prevent damage by contact with the ground surface. If the rolls are to be placed directly on the ground, the local ground surface should be carefully prepared and proof-rolled to minimize the potential for damage. It is good practice to cover the stored rolls with a tarpaulin or plastic sheeting for supplemental protection from the elements.

The polyethylene sleeves of the GCL rolls should be examined for any obvious rips or tears. Sleeve damage should be repaired immediately with adhesive tape or additional plastic sheeting. At this time it is also recommended that the labels be examined and taped to the roll if they were displaced in transit.

SECTION 4
INSTALLATION

This section of the CETCO GCL CQA Manual covers the techniques and procedures to be used for ensuring the quality of a GCL installation. Although some installation techniques are described, this section is *not* an installation guide. Refer instead to CETCO GCL Technical Reference TR-402 for specific GCL installation guidelines. ASTM D 6102 also contains sound GCL installation guidelines.

4.1 Start-Up Assistance

CETCO or its representatives can provide on-site start-up assistance, especially where the installer has no prior GCL installation experience or in which the application is relatively unique. CETCO will work with the on-site engineer and CQA engineer in order to verify that the proper unloading, installation and conformance testing procedures are utilized. CETCO's input is based on extensive experience with GCL installation and on intimate knowledge of the physical characteristics of GCLs. It should be recognized, however, that it is the site engineer's responsibility to implement CETCO's recommendations.

4.2 Equipment

In many projects, the equipment used for unloading the GCL can also be used to install it. Most applications require a vehicle to lift and suspend the roll as it is deployed. Front-end loaders, bulldozers, boom cranes, forklifts, and tracked excavators all have been successfully used for this task. Other, more specialized equipment exists for these operations and may also be used. The equipment for unrolling the GCL should be able to lift the roll and suspend it *freely* such that it does not chafe against the vehicle or the ground. The vehicle must also have the ability to accommodate a spreader bar above the roll of GCL.

The spreader bar should be sufficiently strong to bear the full weight of the GCL roll without bending. Readily available I-beams or T-beams made of structural steel are typically used for this purpose, although steel pipes have also been successfully used. The chains or straps should be checked for their strength before the installation begins and should continually be inspected for wear as the installation continues.

The core pipe should be of the dimensions and strength indicated in Table 1. It has been CETCO's experience that the schedule of the core pipe is not always an accurate indicator of its strength. The type of steel from which the pipe is made, the presence of a longitudinal weld, and the overall length of the pipe all have an influence on its ability to sustain the weight of the GCL. It is essential that the core pipe *does not bend* when the full roll of GCL is suspended from it. Lastly, it is recommended that the core pipe have a means to prevent the chains or straps from slipping off the ends of the pipe. This can be accomplished by using pins or clamps.

It will often be necessary to cut the GCL before the end of the roll or to cut it to fit in certain confined areas. Cutting the GCL requires a *sharp* utility knife. It is very important to maintain the sharpness of the knife blades used for cutting the GCL, in order to prevent tearing its geosynthetic components and damaging the GCL where the cut is made. Frequent blade changes for the utility knives are strongly recommended.

For construction of the bentonite enhanced overlapped seams of the Bentomat products, an acceptable fillet of bentonite can be poured directly from the bags of granular bentonite supplied with each roll of Bentomat, but a watering can (without a sprinkler head) is easier to use and produces a more controlled seam enhancement. A line chalker, such as those used for marking athletic fields, may also be used.

4.3 Field Conditions

At the beginning of each working day, the CQA engineer should confirm that there are no ambient site conditions which could affect the quality of the installation. Specifically, the presence at the job site of excessively high winds, rain, standing water, or snow may be construed as unsuitable weather for GCL installation. There are no temperature restrictions for installing the GCL, however.

Bentomat is not as susceptible as Claymax to damage due to "premature hydration" (i.e., hydration before a confining stress is applied). Although Bentomat will not delaminate when wetted, CETCO nevertheless recommends that it be installed in dry weather as with Claymax. This lessens the potential for damage to the material and ensures that its integrity is not compromised by the swelling of the bentonite. Should the GCL become prematurely hydrated, it urged that CETCO be contacted in order to recommend a project-specific and product-specific recommendation as to whether the GCL must be removed and replaced. CETCO's Technical Reference TR-312 provides a checklist for evaluating GCL that has been hydrated when no confining pressure is present.

4.4 Site Inspection

Prior to each day's installation activities, the site engineer and/or CQA engineer should inspect the work area to ensure that it has been prepared in accordance with the specification and design drawings. Specifically, the design grades should be verified, the slope length and steepness should be checked, the anchor trench dimensions should be measured, and the subgrade should be inspected and approved. Any deviations from the specifications or design drawings should be noted and rectified before the GCL is installed.

The anchor trench is especially important in applications where slopes are present. The anchor trench must meet or exceed the design dimensions but must also be free of any sharp corners or protrusions which could put excessive stress on the GCL. The CQA engineer must ensure that the anchor trench is as carefully prepared as the rest of the subgrade.

4.5 Panel Placement

The unrolling and placement of the GCL should be performed in such a way that the GCL is not damaged or unduly stretched, folded, or creased. The GCL rolls are typically suspended from the front of the vehicle while it travels backwards along the intended path of placement. During this activity, the roll should be able to rotate freely around the core pipe. Excessive friction due to a bent or large-diameter core pipe, or due to contact between the roll and the deployment equipment, may cause undesirable levels of tension to develop. It is necessary that the GCL be deployed in a fully relaxed (but not wrinkled) state.

A common deployment technique when the GCL is placed on slopes is to suspend the roll at the top of the slope while several laborers unroll it as they walk downslope. This is an acceptable technique, but the CQA engineer should verify that excessive tension does not develop on the material and that the underside of the panel is not damaged by friction with the subgrade. Unless the subgrade is acceptably smooth, the GCL should be unrolled over an already-placed panel and then moved laterally into its correct position. Flat-bladed vise grips are very useful for handling and moving unrolled panels.

It is important to ensure that, at the top of a slope, the GCL is properly placed in the anchor trench. After confirming that the trench has been constructed according to the specifications, the GCL should be placed in the trench such that it extends across the trench floor but not up the rear wall of the trench. Excess material if any, should be cut off, *not* folded over on top of the existing material. Proper anchorage will be achieved if and only if the GCL is placed within the trench in this manner.

The orientation of the GCL panels is important. When working in sloping areas, the panels should be positioned such that their long dimension is parallel to the direction of the slope. Panels may only be placed across the slope when the slope is less steep than 4H:1V or when the slope length is very short (less than or equal to 3 m).

4.6 Seaming

Proper field seaming is vital for the liner to function to its maximum abilities. There are three elements of CQA for this important task:

- Verification of the minimum acceptable overlap.
- Verification of the continuity of the accessory bentonite (Bentomat only).
- Verification that there is no dirt in the overlap zone or on the bottom geotextile of the overlying GCL panel.

These elements for field seam CQA are straightforward and require only visual inspection by the CQA engineer. The upper surface of the GCL has two heavy dashed lines on both sides of the panel. The lap lines are 150 mm from the edges of the panel, and the match lines are 250 mm from the edges of the panel. The minimum acceptable overlap is 150 mm. Thus, the installer’s objective is to place the overlying panel *between* the two lines of the underlying panel. The CQA engineer needs only to visually verify that the 150-mm lap line of the underlying panel is not visible. A properly executed seam, therefore, is verified when three dashed lines (not four) are visible at the overlap, as shown in Figure 1.

The hydraulic performance of Bentomat is maximized when the accessory bentonite is placed *continuously* within the overlap zone. Continuity is best achieved when a watering can or other similar device is used. Pouring the bentonite directly from the bag is less effective in this regard. Verification of continuity should be performed visually by the CQA engineer. The CQA engineer should observe the accessory bentonite as it is being placed within the overlap zone and should give verbal approval of the seam before the overlap is flipped back into place.

Bentomat ST, DN, and SDN with Supergroove® have self-seaming capabilities in their longitudinal overlaps (Figure 2) and do not require supplemental bentonite. For these Bentomat products, supplemental bentonite is required for the end-of-panel overlapped seams. For pond applications, supplemental bentonite must be used in longitudinal seams regardless of the CETCO GCL used.

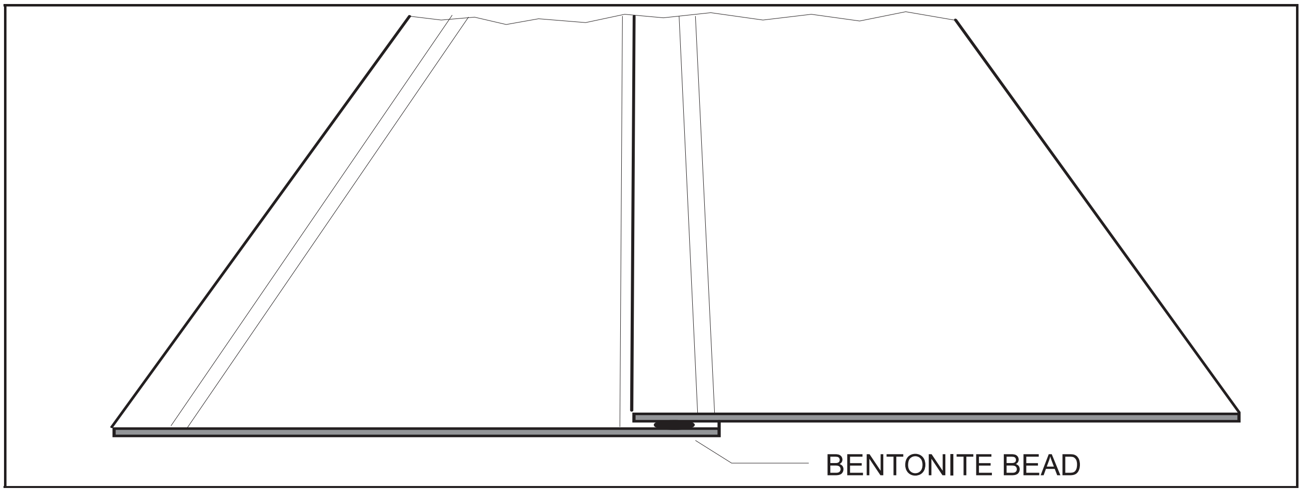

Figure 1. Schematic representation of a properly executed Bentomat field seam.

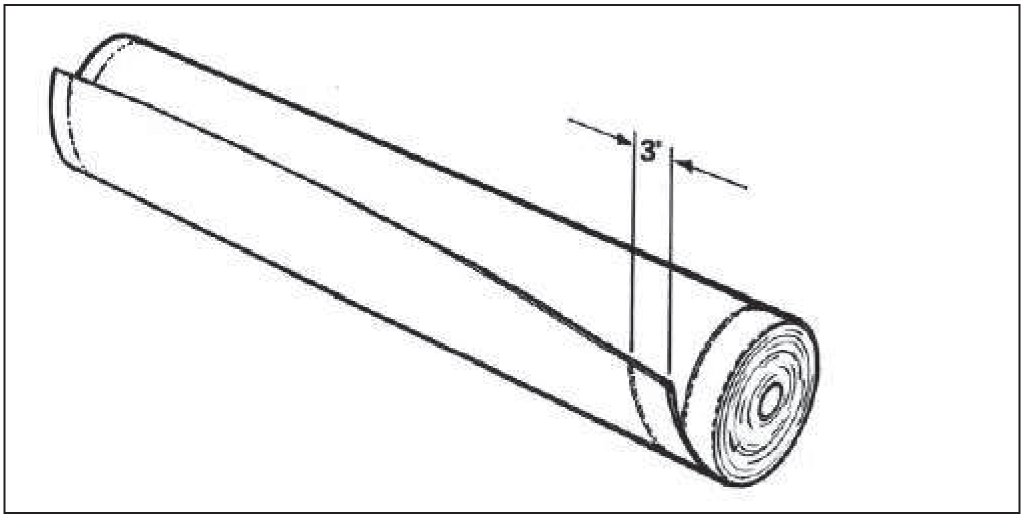

Figure 2. Supergroove Bentomat field seam.

Verification of the cleanliness of the overlap is also required, because dirt can enter the overlap and create a conduit for excessive lateral leakage. This is one reason CETCO recommends that the overlying panel is placed and then its edge flipped back to reveal the overlap zone. Exposing the overlap in this manner forces extra attention on the seam and reveals the presence of loose dirt that may have inadvertently entered the overlap zone or may have become adhered to the bottom geotextile of the overlying panel. The CQA engineer should either verify that no dirt is present or ensure that the dirt is swept out of the overlap.

Verification of the *amount* of bentonite placed at the seam may be achieved by ensuring that one full 22.5 kg bag of granular bentonite is used for the lateral and longitudinal seaming of each roll of GCL. CETCO recommends that a minimum of 375 grams of granular bentonite be applied per lineal meter of seam. If the installer places bentonite at the rate of one bag per roll, this target application rate will be achieved.

The longitudinal overlap for the GCL should be at least 150 mm (Bentomat) and 300 mm (Claymax). Overlaps at the *ends* of the rolls, however, ("transverse" overlaps) should be at least 300 mm (Bentomat) and 600 mm (Claymax) to account for any incidental loss of bentonite that could occur due to excessive handling of this portion of the roll or to stress relaxation after placement. Overlap distances can be increased if unusual site conditions (such as a soft subgrade, or GCL covered only with geomembrane) exist.

4.7 Detail Work

The term "detail work" refers to the placement of GCL around structures such as vertical walls, gas vents, drainage basins, and pipe penetrations. In all of these cases, it is necessary to utilize granular bentonite or a bentonite mastic to create a seal between the GCL and the structure. CQA of these areas involves a visual inspection of the methods used to make the seal. Specific items requiring inspection include:

- Dimensions of the "notch" excavated around the structure.
- Amount of bentonite applied to the detail
- Condition of the GCL at its cut edge (the cut should be clean, not frayed, with little or no bentonite edge loss from the GCL)
- Integrity of the detail as cover material is placed over and around it.

When cutting the GCL, it is important to ensure that the cut is made where the GCL hangs from the roll or where it rests on the subgrade . The GCL cut should *never* be made on the roll itself or when it rests on any other liner system component.

4.8 Damage and Damage Repair

Even when all reasonable protective measures are taken, the GCL may still become damaged during shipping and handling or during installation. This section provides instructions on assessing and managing the damaged materials.

4.8.1 Damage From Shipping and Handling

Occasionally, a GCL roll will arrive at a job site with its protective plastic sleeve torn due to movement during transit. This roll should be inspected for damage in the area where the sleeve was torn. If the geotextile under the torn sleeve is also torn, The outermost wrap of GCL on the roll should be unwound and discarded when the roll is installed. It is not necessary to consider the entire roll unusable. It is important, however, to mark the roll in order to alert the installer that the initial wrap should be cut away and discarded, because the damaged geotextile may be hidden from view when the GCL is unrolled. It is remotely possible that further layers of GCL on the roll could be similarly damaged. If this happens, additional wraps may be unrolled and discarded prior to placement.

Damage due to poor handling may occur as a result of accidentally dropping a suspended roll onto the ground or using weak core pipes that bend when the GCL is lifted. These activities can cause damage not just to the outer wrap of GCL but to the entire roll. If such damage occurs, the rolls should be clearly marked and moved away from the storage area. The CQA engineer should ensure that procedures are immediately implemented in order to prevent the recurrence of this problem. The CQA engineer should also contact CETCO to help make a determination as to whether the mis-handled GCL is acceptable for use on the project.

4.8.2 Damage From Installation Activities

The more commonly observed incidents of damage occur during installation, as a result of inadvertent contact by heavy equipment. Because this type of damage will potentially have the largest overall effect on the integrity of the liner system, CETCO strongly recommends that equipment operating on or near the GCL *be monitored continuously.*

Equipment operators should be made fully aware of the importance of their actions and should be encouraged to notify the CQA engineer directly if they suspect at any time that the liner may have become damaged by their equipment. Close communication among everyone involved in the installation will help to ensure that this type of damage is reported and repaired.

Repeated passes by loaded dump trucks over GCL, which has minimal cover, can cause damage. It is therefore preferred to prevent potential for such damage by placing the GCL over these high-traffic areas *after* cover material delivery is largely completed. If this is not possible, then extra cover should be placed over high-traffic areas. At least 600-900 mm of screened, cohesive soil is recommended.

Should damage occur to the already-installed GCL, the following procedures should be followed:

1. Remove equipment from the damaged area and notify the CQA engineer.
2. *Manually* clean away all cover material within a 600-mm radius of the damaged area. Use a broom to sweep away the remaining dirt in order to make the area as clean as possible.
3. If necessary, repair the subgrade to its original conditions. Replace the torn/damaged GCL as closely as possible to its original position.
4. Place a bead of granular bentonite or bentonite paste at the minimum rate of 500 g per lineal meter around the damaged area.
5. Cut a patch of new GCL to fit over the damaged area and extending 600 mm beyond it.

6. Place the patch over the damaged area and carefully backfill over the patch.

Note that it is necessary only to repair the damaged portion of the GCL. It is usually not necessary to remove and replace the entire panel, unless the damage has occurred on a slope. In this case, slope stability may be compromised and the site engineer should be contacted to help determine whether a repair is acceptable.

SECTION 5
PLACEMENT OF COVER MATERIALS

As mentioned previously, the proper placement of cover on the GCL is crucial to the overall success of the installation. This section of the Bentomat CQA manual includes recommended materials and procedures, which will help to ensure that the integrity of the GCL is not compromised when it is covered.

Regardless of the nature of the cover material used, it should be placed as soon as possible after the GCL has been deployed. The efforts of placing the GCL and placing the final cover should be coordinated to the extent that only as much GCL as can be covered should be deployed in one working day. This will prevent premature hydration and will greatly reduce the chances for incidental damage to the GCL during other activities.

5.1 Soil/Stone Cover

When a GCL is the sole liner system component, soil or stone cover *must* be placed over it to provide protection from physical damage, erosional forces, and degradation by UV light. The presence of cover also provides a confining stress, which allows the overlapped seam to perform properly and enhances the long-term physical integrity of the material. Lastly, the cover may provide a base for vehicular traffic. Because it serves so many functions, proper placement and CQA of the soil/stone cover is essential.

Frequently used cover materials include sand, gravel, crushed stone, and common earth fill. Regardless of the type of material selected for the cover, it should be free of large stones (greater than 50 mm in diameter), sticks, and any other materials, which could cause puncture or tearing. The source of all cover material should be identified in order to ascertain its suitability well in advance of the installation.

In addition to particle size, the *angularity* of a crushed stone or gravel will impact the construction survivability of the GCL. It is preferred that relatively rounded materials be utilized. If these materials are not available, then extra caution must be taken during cover placement. Dumping the cover from a loader bucket positioned high above the GCL is unacceptable. The cover should be gently placed from as low a height as possible. Vehicular traffic should also be restricted if particularly angular or abrasive material is used. If there is some doubt as to the suitability of a potential cover material, a representative sample should be submitted to CETCO for analysis.

With respect to the equipment used to place the protective cover, it is strongly recommended that no heavy equipment come in direct contact with the GCL. Obviously, tracked equipment will damage the liner. In some cases, however it is necessary to drive equipment directly on the GCL. This can be accomplished with low-pressure, *rubber-tired* equipment. Permission to do so will be granted by CETCO through the CQA engineer on a case-by-case basis *only* and will include restrictions on the equipment itself and on the type of movements the vehicle may make on the GCL.

The chemical nature of the cover soil must also be considered. The use of fine-grained, calcareous soil or stone is strongly discouraged due to the potential for an adverse reaction with the sodium bentonite contained in the GCL.

The cover material placed as backfill in the anchor trench should be of the same quality as the rest of the backfill. It is especially important that the anchor trench backfill be compacted either by hand tamping or by the use of a small walk-behind compactor. Compaction should be performed over each 150-mm lift of backfill placed in the anchor trench.

5.2 Geosynthetic Cover

A geomembrane or other geosynthetic liner system component is often placed over the GCL. Caution must be used during this activity to prevent GCL damage. Again, it is strongly recommended that no heavy equipment directly contact the GCL, but exceptions can be made on a project-specific basis.

A special precaution should be taken when textured geomembrane is installed directly over the GCL in a composite liner system. Because considerable friction may develop between the geomembrane and the GCL, it is difficult to pull the geomembrane into position for welding to adjacent sheets. A smooth "slip sheet" can be used to provide a low-friction sliding surface for the geomembrane until it is in position for welding.

SECTION 6
CONFORMANCE TESTING

Conformance testing is necessary in order to verify that the materials installed meet the requirements set forth in the specification. Although CETCO performs regular testing on its GCLs as part of its manufacturing QA/QC program, the engineer may require additional testing at the job site. This section lists several tests, which may be utilized to verify the quality of the delivered materials and the quality of the installation of those materials.

6.1 Bentonite Mass Per Unit Area

A relatively simple test to verify that the specified amount of bentonite has been encapsulated in the GCL is to measure the bentonite mass per unit area of representative samples cut from delivered rolls. The results of this test may be used in conjunction with the results of the bentonite swell test described in Section 6.2 to arrive at an indirect verification of the hydraulic performance of the GCL.

ASTM D 5993 provides procedures for performing the mass per unit area test. After the correction for geotextile mass is made, there should be at least 3,600 g of bentonite contained within the GCL per square meter. This is CETCO's minimum average roll value (MARV) for bentonite content of all of its GCLs. These values are always subject to change, so please refer to GCL Technical Reference No. TR-404 for the most recent list of certified physical GCL properties.

If for any reason the resulting mass per unit area values do not meet the required MARVs, the corresponding rolls should be set-aside for additional inspection and testing. CETCO should be notified to assist in resolving the problem if it persists.

6.2 Bentonite Swell Index and Fluid Loss

The swell index and fluid loss of the bentonite are two of the most important indicators of its ability to function as a barrier material. ASTM D 5890 provides a detailed free swell testing procedure used by CETCO. CETCO's MARV requirement for the bentonite is 24 mL/2g. ASTM D5891 provides a detailed fluid loss testing procedure. CETCO's maximum requirement for fluid loss of the bentonite is 18 ml. As with the mass per unit area test described in Section 6.1, if these values are not achieved in conformance testing, the corresponding rolls should be set aside for additional inspection and testing. CETCO should be notified to assist in resolving the problem if it persists.

6.3 Other Conformance Tests

Other conformance tests may be conducted at the request of the on-site engineer or the CQA engineer on a project specific basis. ASTM D6495 suggests grab tensile strength and index flux/permeability (as per ASTM D 5887), although it should be cautioned that rapid "real-time" results of index flux/permeability are not possible due to the time required to achieve steady-state permeability values. Thus, it is difficult to use permeability testing as a pass/fail criterion for GCL acceptance at the job site.

Also, the laminated GCLs are not easily tested for index flux/permeability due to potential sidewall leakage around the membrane. CETCO has a special setup procedure for its laminated GCLs in TR-302.

Lastly, it should be recognized that field-scale test pads and infiltrometer tests are typically *not* performed in GCL projects. This contrasts with compacted clay liner (CCL) projects, in which, for two reasons, field-scale data is almost always required. First, field data for CCL projects is necessary because there are many variables involved in their construction (compactor weight, speed, number of passes; soil type; moisture content; lift thickness; etc.). It is therefore necessary to build a test pad to ensure that the construction materials and methods intended for the project will provide the required level of performance. Second, laboratory test results and field test results may vary significantly with CCLs due to the difficulties in retrieving representative, undisturbed samples. This factor also warrants that field data be obtained for CCL projects.

With GCL installations, however, there are very few construction-related variables. Additionally, the GCL that is tested for permeability in the laboratory is the *same* material deployed in the field. For this reason, a GCL such as Bentomat or Claymax does not require a field permeability test.

SECTION 7
DOCUMENTATION

Thorough documentation of all CQA activities and tests is necessary in order to provide a written record that the GCL has been properly installed. The CQA documentation package for a GCL installation should include the following items:

- Bills of lading and corresponding packing list confirming receipt of all GCL installed at the site.
- A panel layout drawing in which the GCL roll numbers are keyed to their location in the field. Locations where damage was encountered and repaired should also be marked.
- The roll numbers from which samples were taken for conformance tests, along with the results of those tests.
- A daily report or diary of the activities undertaken at the site during construction.
- Certification that the requirements for the subgrade and for the cover material were achieved.
- A compilation of all CQA checklists completed during the installation.
- The manufacturing quality control (MQC) certification and accompanying test data.
- A description of deviations, if any, made to the original CQA plan during the installation.
- Photographs of the GCL during installation.

CETCO provides the MQC certification. All other items on the above list are the responsibility of the CQA engineer.

APPENDIX A
List of Applicable ASTM Standards

ASTM D 5887, "Standard Test Method for Measurement of the Index Flux Through Saturated Geosynthetic Clay Liner Specimens Using a Flexible Wall Permeameter," ***Annual Book of ASTM Standards, Vol. 4.09,*** **American Society for Testing and Materials, W. Conshohocken, PA.**

This method describes the specimen preparation, stress and gradient conditions, and testing procedures to be used for determining the flux (flow per unit area) through GCLs. Adherence to the specimen preparation procedures presented will help to minimize sidewall leakage, a common problem when testing thin barriers. This is an index test designed to determine product acceptability and uses a maximum confining stress of 35 kPa (5 psi) and a hydraulic gradient of 14 kPa (2 psi).

ASTM D 5888, "Standard Guide for Storage and Handling of Geosynthetic Clay Liners," ***Annual Book of ASTM Standards, Vol. 4.09,*** **American Society for Testing and Materials, W. Conshohocken, PA.**

This is a guide for the safe handling of GCL rolls at a job site, identifying the equipment and techniques typically employed to unload the material from delivery trucks and to place it in a dedicated storage area. Procedures are also presented for proper storage of the GCL in order to minimize the potential for product damage while in storage.

ASTM D 5889, "Standard Practice for Quality Control of Geosynthetic Clay Liners," ***Annual Book of ASTM Standards, Vol. 4.09,*** **American Society for Testing and Materials, W. Conshohocken, PA.**

Test methods and testing frequencies are presented for manufacturing quality control (MQC) of GCLs. This standard practice includes conformance tests to be performed on the GCL components (bentonite and geotextiles and/or geomembranes) as well as tests to be performed on the finished GCL product. Special procedures for GCL permeability/flux testing require the manufacturer to provide an historical database to demonstrate the consistency of the hydraulic performance of the finished product and to justify the reduced need for frequent MQA permeability testing.

ASTM D 5890, "Standard Test Method for Swell Index Measurement of Clay Mineral Component of Geosynthetic Clay Liners," ***Annual Book of ASTM Standards, Vol. 4.09,*** **American Society for Testing and Materials, W. Conshohocken, PA.**

This test method was adapted from the basic elements of a swell test presented in the USP/NF (United States Pharmacopeia/National Formulary). Two grams of dried and powdered bentonite are slowly dropped into a graduate cylinder containing 100 mL of distilled water. The swell value in mL is recorded after 24 hours, by reading the value on the graduate cylinder at the clay/water interface.

APPENDIX A (continued)
List of Applicable ASTM Standards

ASTM D 5891, "Standard Test Method for Measurement of Fluid Loss of Clay Mineral Component of Geosynthetic Clay Liners."

This test method was adapted from the API (American Petroleum Institute) Procedure 13A/13B for bentonite. A bentonite slurry is created, aged, and then filtered in a pressurized cell. The amount of water passing through the filter cake in a specified time interval is recorded as the filtrate loss or fluid loss. The test indicates the clay's general ability to function as a barrier to liquids.

ASTM D 5993, "Standard Test Method for Measuring the Mass per Unit Area of Geosynthetic Clay Liners."

This test method describes how to measure the bentonite mass per unit area of a GCL sample. A GCL specimen of a certain minimum area is weighed, oven-dried, and weighed again. The dry weight of the specimen, minus the nominal weight of the geosynthetic component(s), is then divided by the area of the specimen. The moisture content of the specimen is determined by subtracting the dry weight from the wet weight.

ASTM D 6072, "Standard Guide for Obtaining Samples of Geosynthetic Clay Liners."

Presents procedures for obtaining representative samples of GCL material for laboratory testing purposes. These samples may be obtained either at the factory or in the field. Procedures for packaging and protecting the sample are also included to prevent the possibility of damage in transit to the laboratory.

ASTM D 6102, "Standard Guide for Installation of Geosynthetic Clay Liners."

Provides detailed recommendations for the proper installation of GCLs. Discusses the necessary site conditions, equipment, and techniques for installing GCLs without damaging them. Includes recommendations on panel placement, overlaps, and special considerations for slopes. Also discusses the preferred types of soil cover and equipment used to apply this cover.

ASTM D 6243, "Standard Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method."

This test method covers a procedure for determining the internal shear resistance of a GCL or the interface shear resistance between the GCL and an adjacent material under a constant rate of displacement or constant stress.

ASTM D 6496, "Standard Test Method for Determining Average Bonding Peel Strength Between Top and Bottom Layers of Needle-Punched Geosynthetic Clay Liners."

This test method was adapted from ASTM D 4632 for grab strength testing of geotextiles. The method covers the laboratory determination of the average bonding strength between the top and bottom layers of a sample of a GCL. These results provide an indication of a GCL's internal reinforcement and internal shear strength.

APPENDIX A (continued)
List of Applicable ASTM Standards

ASTM D 6768, "Standard Test Method for Tensile Strength of Geosynthetic Clay Liners."

This test method was adapted from ASTM D 4632 for grab strength testing of geotextiles. The test method establishes the procedures for the measurement of tensile strength of a GCL. This test method is strictly an index test method to be used to verify the tensile strength of GCLs. Results from this test method should not be considered as an indication of actual or long-term performance of the geosynthetic in field applications.

ASTM D 6495, "Standard Guide for Acceptance Testing Requirements for Geosynthetic Clay Liners".

Provides guidelines for acceptance testing requirements for GCLs, including test methods and verifications.

APPENDIX B
CETCO GCL Construction Quality Assurance Checklist

Project Name/Number:____

CQA Inspector:____

Date:____________________Weather:_____________________________________

STORAGE AREA

________ Rolls covered/tarped
________ Rolls labeled
________ No standing water present
________ Packaging intact/repaired
________ Accessory bentonite protected

MATERIALS RECEIVED TODAY

________ Packaging intact
________ Rolls inspected for damage--
none found
________ Damage suspected (indicate
roll numbers and nature of
damage ____________________________
____
____

SITE INSPECTION

________ Subgrade surface acceptable
________ Installation area dry
________ Anchor trenches acceptable
________ Design grades achieved
________ Cover soil acceptable (as applicable)

INSTALLATION

________ Number of rolls deployed today
(attach list of roll numbers)
________ Anchor trench fill compacted
________ Min. seam overlap achieved
________ All seams visually inspected
________ Seam bentonite added (as applicable)
________ All detail work inspected
________ Downslope panel orientation
________ All mat covered at end of day
________ Storage area maintained

INSTALLATION EQUIPMENT

________ Core pipe straight
________ Spreader bar straight
________ Chains/Straps inspected
________ Knife blades replaced
________ Seaming clay supply available

CONFORMANCE TESTING

Bentonite Mass/Area:

Bentomat Roll No.	Bentonite (g/sm)	Pass/ Fail?

Bentonite Swell:

Bentomat Roll No.	Final Swell Value (mL/2g)	Pass/ Fail?

NOTES/OBSERVATIONS

____
____
____

NOTE:

This checklist is intended to serve as a *guideline* for the CQA engineer to use in the development of a project-specific or company-specific CQA plan. The checklist is not all-inclusive. The items presented in this list are those that CETCO feels are the most important for the proper installation of Bentomat.

BENTOMAT® INSTALLATION GUIDELINES

GEOSYNTHETIC CLAY LINERS

CETCO®

BENTOMAT®

GEOSYNTHETIC CLAY LINERS

CONTENTS

NOTICE: THIS DOCUMENT IS INTENDED FOR USE AS A GENERAL GUIDELINE FOR THE INSTALLATION OF CETCO GCLS. THE INFORMATION AND DATA CONTAINED HEREIN ARE BELIEVED TO BE ACCURATE AND RELIABLE. CETCO MAKES NO WARRANTY OF ANY KIND AND ACCEPTS NO RESPONSIBILITY FOR THE RESULTS OBTAINED THROUGH APPLICATION OF THIS INFORMATION. INSTALLATION GUIDELINES ARE SUBJECT TO PERIODIC CHANGES. PLEASE CONSULT OUR WEBSITE @ WWW.CETCO.COM/LT FOR THE MOST RECENT VERSION.

SECTION 1
INTRODUCTION

1.1
This document provides procedures for the installation of CETCO GCLs in a manner that maximizes safety, efficiency, and the physical integrity of the GCL.

1.2
These guidelines are based upon many years of experience at a variety of sites and should be generally applicable to any type of lining project using CETCO GCLs. Variance from these guidelines is at the engineer's discretion.

1.3
The performance of the GCL is wholly dependent on the quality of its installation. It is the installer's responsibility to adhere to these guidelines, and to the project specifications and drawings as closely as possible. It is the engineer's and owner's responsibility to provide construction quality assurance (CQA) for the installation. This will ensure that the installation has been executed properly. This document covers only installation procedures.

1.4
For additional guidance, refer to ASTM D5888 (Standard Guide For Storage and Handling of Geosynthetic Clay Liners) and ASTM D 6102 (Standard Guide For Installation of Geosynthetic Clay Liners).

SECTION 2
EQUIPMENT REQUIREMENTS

2.1
CETCO GCLs are delivered in rolls typically 2,600-2,950 lbs (1180-1340 kg). Roll dimensions and weights will vary with the dimensions of the product ordered. It is necessary to support this weight using an appropriate core pipe, as indicated in Table 1. For any installation, the core pipe must not deflect more than 3 inches (75 mm), as measured from end to midpoint when a full GCL roll is lifted.

2.2
Lifting chains or straps appropriately rated should be used in combination with a spreader bar made from an I-beam, as shown in Figure 1.

2.3
The spreader bar ensures that lifting chains or straps do not chafe against the ends of the GCL roll, allowing it to rotate freely during installation. Spreader bar and core pipe kits are available through CETCO.

2.4
A front end loader, backhoe, dozer, or other equipment can be utilized with the spreader bar and core pipe or slings. Alternatively, a forklift with a "stinger" attachment may be used for on-site handling. A forklift without a stinger attachment should not be used to lift or handle the GCL rolls. Stinger attachments (Figures 2-4) are specially fabricated to fit various forklift makes and models.

Table 1: Core Requirements

Product	Nominal GCL Roll Size Lenth X Diameter	Typical GCL Roll Weight	Interior Core Size	Core Pipe Length x Diameter	Minimum Core Pipe Strength
BENTOMAT DN, SDN	16' x 24" (4.9 m x 610 mm)	2,650 lbs. (1204 kg)	3 3/4" (100 mm)	20' x 3.5" O.D. (6.1 m x 89 mm)	XXH
BENTOMAT ST	16' x 24" (4.9 m x 610 mm)	2,650 lbs. (1204 kg)	3 3/4" (100 mm)	20' x 3.5" O.D. (6.1 m x 89 mm)	XXH
BENTOMAT STM	16' x 32" (4.9 m x 814 mm)	2,500 lbs. (1130 kg)	3 3/4" (100 mm)	20' x 3.5" O.D. (6.1 m x 89 mm)	XXH
BENTOMAT 200R	16' x 24" (4.9 m x 610 mm)	2,650 lbs. (1204 kg)	3 3/4" (100 mm)	20' x 3.5" O.D. (6.1 m x 89 mm)	XXH
BENTOMAT CLT	16' x 26" (4.9 m x 660 mm)	2,650 lbs. (1204 kg)	3 3/4" (100 mm)	20' x 3.5" O.D. (6.1 m x 89 mm)	XXH
BENTOMAT CL	16' x 25" (4.9 m x 635 mm)	2,650 lbs. (1204 kg)	3 3/4" (100 mm)	20' x 3.5" O.D. (6.1 m x 89 mm)	XXH
BENTOMAT 600 CL	16' x 25" (4.9 m x 635 mm)	2,700 lbs. (1227 kg)	3 3/4" (100 mm)	20' x 3.5" O.D. (6.1 m x 89 mm)	XXH

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FIGURE 1 -SPREADER BAR ASSEMBLY

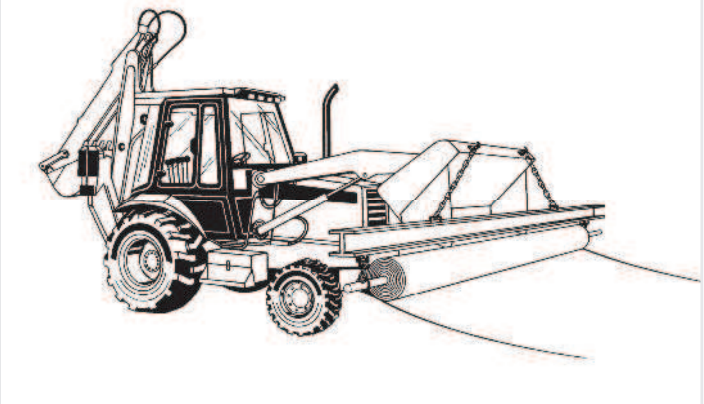


FIGURE 2 - HOOK MOUNT

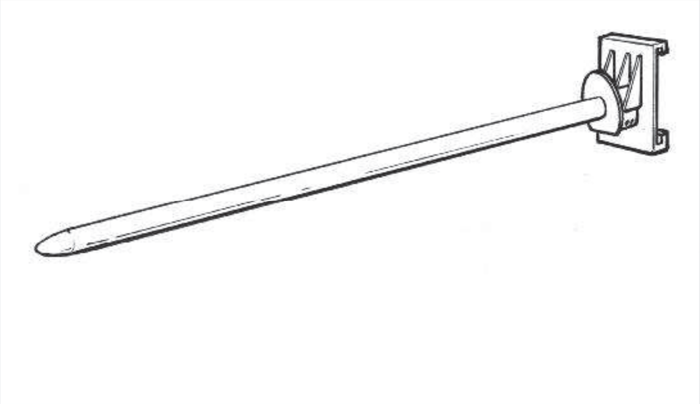


FIGURE 3 - FORK MOUNT (WITH FORK POCKETS)

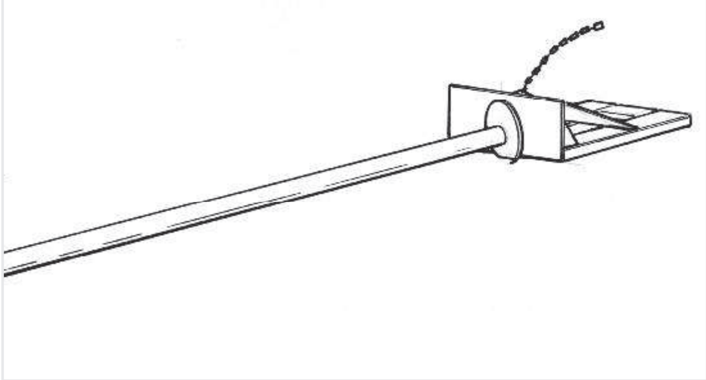
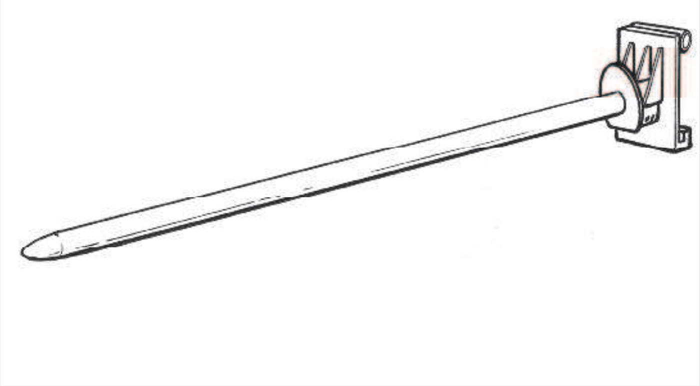


FIGURE 4 - PIN MOUNT



2.5

When installing over certain geosynthetic materials, a 4 wheel, all-terrain vehicle (ATV) can be used to deploy the GCL. An ATV can be driven directly on the GCL provided that no sudden stops, starts, or turns are made.

2.6

Additional equipment needed for installation of CETCO GCLs includes:

- Utility knife and spare blades (for cutting the GCL)
- Granular bentonite for end-of-roll GCL seams and for sealing around structures and details
- Waterproof tarpaulins (for temporary cover on installed material as well as for stockpiled rolls)
- Optional flat-bladed vise grips (for positioning the GCL panel by hand)

2.7

The CETCO EASY ROLLER™ GCL Deployment System is a preferred method of installing geosynthetic clay liners. Use of the EASY ROLLER system eliminates the need for spreader bars and heavy core pipes. Installation speed and worker safety are also significantly increased. For further details, contact CETCO.

SECTION 3
SHIPPING, UNLOADING, & STORAGE

3.1

All lot and roll numbers should be recorded and compared to the packing list. Each roll of GCL should also be visually inspected during unloading to determine if any packaging has been damaged. Damage, whether obvious or suspected, should be recorded and the affected rolls marked.

3.2

Major damage suspected to have occurred during transit should be reported to the carrier and to CETCO immediately. The nature of the damage should also be indicated on the bill of lading, with specific lot and roll numbers noted. Accumulation of some moisture within roll packaging is normal and does not damage the product.

3.3

The party directly responsible for unloading the GCL should refer to this manual prior to shipment to ascertain the appropriateness of their unloading equipment and procedures. Unloading and on-site handling of the GCL should be supervised.

3.4

In most cases, CETCO GCLs are delivered on flatbed trucks. There are three methods of unloading: core pipe and spreader bar, slings, or stinger bar. To unload the rolls from the flat-bed using a core pipe and spreader bar, first insert the core pipe through the core tube. Secure the lifting chains or straps to each end of the core pipe and to the spreader bar mounted on the lifting equipment. Hoist the roll straight up and make sure its weight is evenly distributed so that it does not tilt or sway when lifted.

3.5

All CETCO GCLs are delivered with two 2'x 12' (50 mm x 3.65 mm) Type V polyester endless slings on each roll. Before lifting, check the position of the slings. Each sling should be tied off in the choke position, approximately one third (1/3) from the end of the roll. Hoist the roll straight up so that it does not tilt or sway when lifted.

3.6

In some cases, GCL rolls will be stacked in three pyramids on flatbed trucks. If slings are not used, rolls will require unloading with a stinger bar and extendible boom fork lift. Spreader bars will not work in this situation because of the limited access between the stacks of GCL. Three types of stingers are available from CETCO, a hook mount, fork mount and pin mount (Figures 2-4). To unload, guide the stinger through the core tube before lifting the GCL roll and removing the truck.

3.7

An extendable boom fork lift with a stinger bar is required for unloading vans. Rolls in the nose and center of the van should first be carefully pulled toward the door using the slings provided on the rolls.

3.8

Rolls should be stored at the job site away from high-traffic areas but sufficiently close to the active work area to minimize handling. The designated storage area should be flat, dry, and stable. Moisture protection of the GCL is provided by its packaging; however, based on expected weather conditions, an additional tarpaulin or plastic sheet may be required for added protection during prolonged outdoor storage.

3.9

Rolls should be stacked in a manner that prevents them from sliding or rolling. This can be accomplished by chocking the bottom layer of rolls. Rolls should be stacked no higher than the height at which they can be safely handled by laborers (typically no higher than four layers of rolls). Rolls should never be stacked on end.

SECTION 4
SUBGRADE PREPARATION

4.1

Subgrade surfaces consisting of granular soils or gravels are not acceptable due to their large void fraction and puncture potential. In applications where the GCL is the only barrier, subgrade soils should have a particle-size distribution of at least 80 percent finer than the #60 sieve (0.25 mm). In other applications, subgrade soils should range between fines and 1 inch (25 mm). In high-head applications (greater than 1 foot or 30.48 cm), CETCO recommends a membrane-laminated GCL (BENTOMAT CLT, BENTOMAT CL, or BENTOMAT 600 CL).

4.2

When the GCL is placed over an earthen subgrade, the subgrade surface must be prepared in accordance with the project specifications. The engineer's approval of the subgrade must be obtained prior to installation. The finished surface should be firm and unyielding, without abrupt elevation changes, voids, cracks, ice, or standing water.

4.3

The subgrade surface must be smooth and free of vegetation, sharp-edged rocks, stones, sticks, construction debris, and other foreign matter that could contact the GCL. The subgrade should be rolled with a smooth-drum compactor to remove any wheel ruts greater than 1 inch in depth, footprints, or other abrupt grade changes. Furthermore, all protrusions extending more than 0.5 inch (12 mm) from the subgrade surface shall be removed, crushed, or pushed into the surface with a smooth-drum compactor. The GCL may be installed on a frozen subgrade, but the subgrade soil in the unfrozen state should meet the above requirements.

SECTION 5
INSTALLATION

5.1

GCL rolls should be taken to the work area of the site in their original packaging. The orientation of the GCL (i.e., which side faces up) may be important if the GCL has two different types of geosynthetics. Check with the project engineer to determine if there is a preferred installation orientation for the GCL. If no specific orientation is required, allow the roll to unwind from the bottom rather than pulling from the top (Figure 5A). The arrow sticker on the plastic sleeve indicates the direction that the GCL will naturally unroll when placed on the ground (Figure 6). Prior to deployment, the packaging should be carefully removed without damaging the GCL.

5.2

Equipment which could damage the GCL should not be allowed to travel directly on it. Therefore, acceptable installation may be accomplished whereby the GCL is unrolled in front of backwards-moving equipment (Figure 7). If the installation equipment causes rutting of the subgrade, the subgrade must be restored to its originally accepted condition before placement continues.

5.3

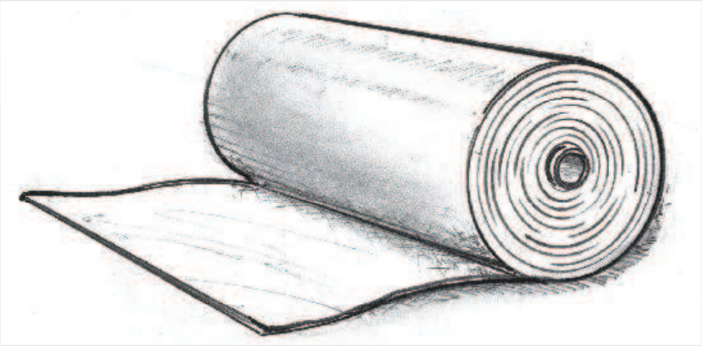
If sufficient access is available, GCL may be deployed by suspending the roll at the top of the slope, with a group of laborers pulling the material off of the roll, and down the slope (Figure 8).

5.4

GCL rolls should not be released on the slope and allowed to unroll freely by gravity.

FIGURE 5 A & B

“NATURAL’ ORIENTATION (5A)



TOP OF THE ROLL (5B)

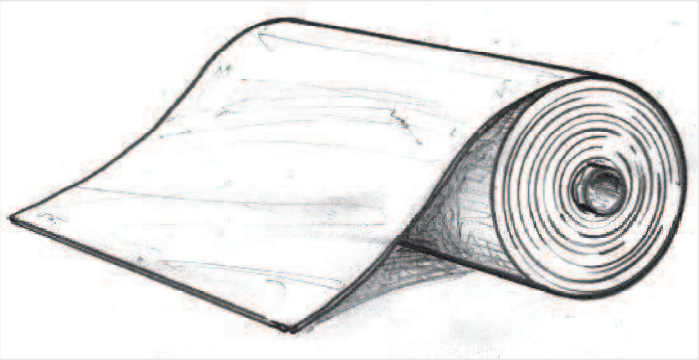


FIGURE 6 - DIRECTION TO UNROLL GCL ON GROUND PER FIGURE 5A

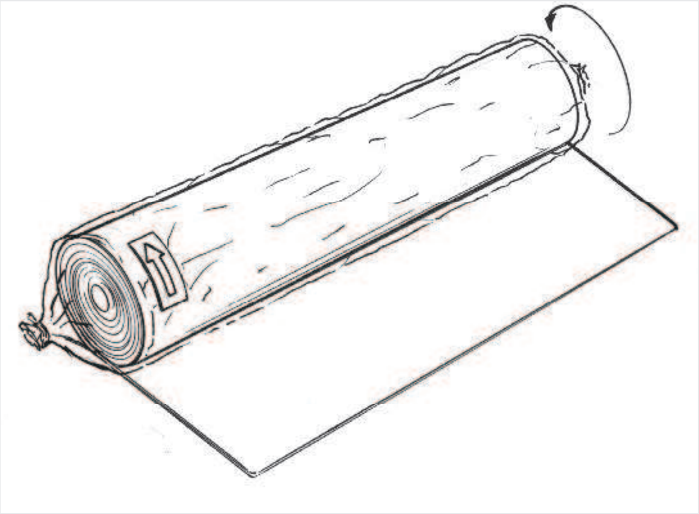


FIGURE 7 - TYPICAL BENTOMAT® INSTALLATION TECHNIQUE

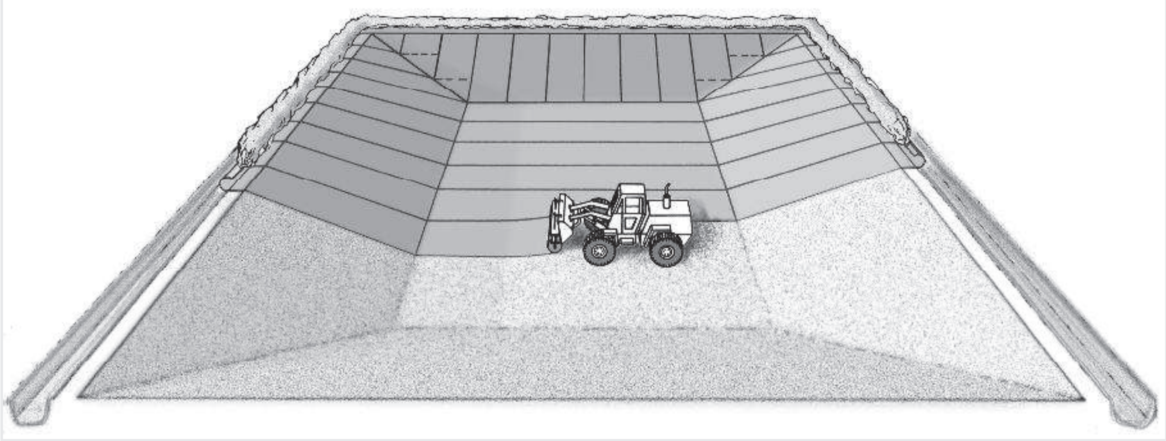
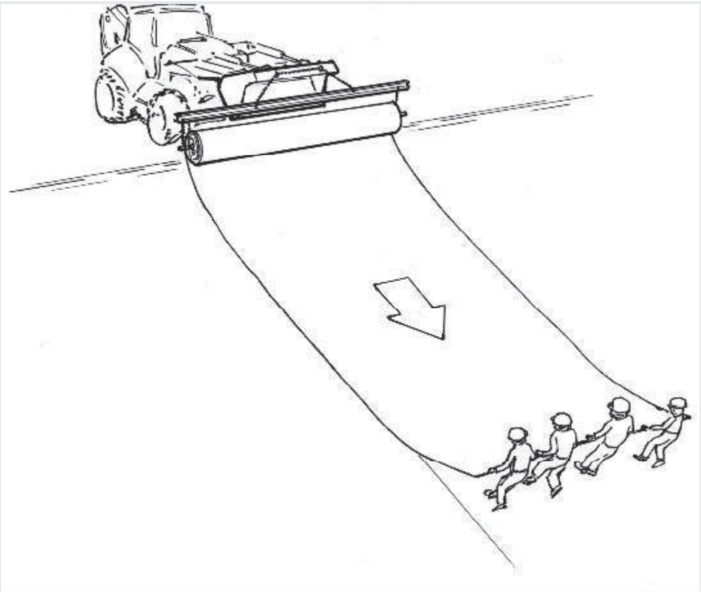


FIGURE 8 - UNROLLING BENTOMAT



5.5

Care must be taken to minimize the extent to which the GCL is dragged across the subgrade to avoid damage to the bottom surface of the GCL. Care must also be taken when adjusting BENTOMAT CLT panels to avoid damage to the geotextile surface of one panel of GCL by the textured sheet of another panel of GCL. A temporary geosynthetic subgrade cover commonly known as a slip sheet or rub sheet may be used to reduce friction damage during placement.

5.6

The GCL should be placed so that seams are parallel to the direction of the slope. End-of-panel seams should also be located at least 3 ft (1 m) from the toe and crest of slopes steeper than 4H:1V. End-of-roll seams on slopes should be used only if the liner is not expected to be in tension.

5.7

All GCL panels should lie flat, with no wrinkles or folds, especially at the exposed edges of the panels. When BENTOMAT geosynthetic clay liners with SUPERGROOVE® is repositioned, it should be gripped inside the SUPERGROOVE by folding the edge.

5.8

The GCL should not be installed in standing water or during rainy weather. Only as much GCL shall be deployed as can be covered at the end of the working day with soil, geomembrane, or a temporary waterproof tarpaulin. The GCL shall not be left uncovered overnight. If the GCL is hydrated when no confining stress is present, it may be necessary to remove and replace the hydrated material. CETCO recommends that premature hydration be evaluated on a case-by-case basis. The project engineer, CQA inspector, and CETCO TR-312 should be consulted for specific guidance if premature hydration occurs. The type of GCL, duration of exposure, degree of hydration, location in the liner system, and expected bearing loads should all be considered.

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In many instances, a needlepunch reinforced GCL may not require removal/replacement if the following are true:

- ► The geotextiles have not been separated, torn, or otherwise damaged
- ► There is no evidence that the needlepunching between the two geotextiles has been compromised
- ► The GCL does not leave deep indentations when stepped upon
- ► Overlapped seams with bentonite enhancement (see Section 7) are intact

5.9

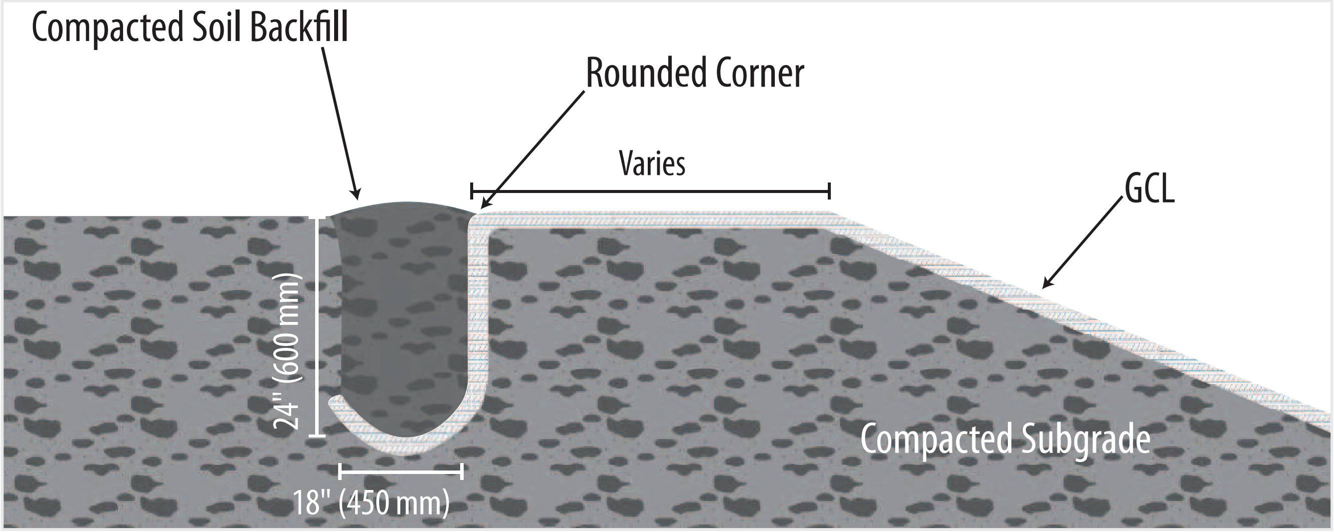
For the convenience of the installer, hash marks are placed on BENTOMAT goesynthetic clay liners every 5' (1.5 m) of length.

SECTION 6 ANCHORAGE

6.1

If required by the project drawings, the end of the GCL roll should be placed in an anchor trench at the top of a slope. The front edge of the trench should be rounded to eliminate any sharp corners that could cause excessive stress on the GCL. Loose soil should be removed or compacted into the floor of the trench.

FIGURE 9 - TYPICAL ANCHOR TRENCH DESIGN



6.2

If a trench is used for anchoring the end of the GCL, soil backfill should be placed in the trench to provide resistance against pullout. The size and shape of the trench, as well as the appropriate backfill procedures should be in accordance with the project drawings and specifications. Typical dimensions are shown in Figure 9.

6.3

The GCL should be placed in the anchor trench such that it covers the entire trench floor but does not extend up the rear trench wall.

6.4

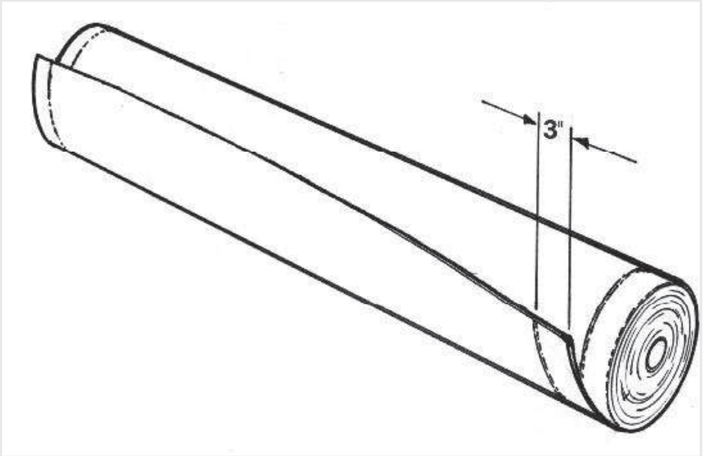
Sufficient anchorage may alternately be obtained by extending the end of the GCL roll back from the crest of the slope, and placing cover soil. The length of this "runout" anchor should be prepared in accordance with project drawings and specifications.

SECTION 7 SEAMING

7.1

GCL seams are constructed by overlapping adjacent panel edges and ends. Care should be taken to ensure that the overlap zone is not contaminated with loose soil or other debris. BENTOMAT 200R, BENTOMAT ST, BENTOMAT DN, and BENTOMAT SDN have SUPERGROOVE® which provides self-seaming capabilities in their longitudinal overlaps, and therefore do not require supplemental bentonite. However, for pond applications, supplemental bentonite must be used in longitudinal seams, regardless of the CETCO GCL.

FIGURE 10 - SUPERGROOVE®



7.2

Longitudinal seams should be overlapped a minimum of 6 inches (150 mm) for BENTOMAT geosynthetic clay liners. For high-head applications (greater than 1 foot or 20.48 cm) involving BENTOMAT CL, BENTOMAT CLT, or BENTOMAT 600 CL, a minimum longitudinal seam overlap of 12 inches (300 mm) and supplemental bentonite (per Section 7.6) is recommended.

7.3

End-of-panel overlapped seams should be overlapped 24 inches (600 mm) for BENTOMAT geosynthetic clay liners.

7.4

End-of-panel overlapped seams are constructed such that they are shingled in the direction of the grade to prevent runoff from entering the overlap zone. End-of-panel seams on slopes are permissible, provided adequate slope stability analysis has been conducted (i.e., the GCL is not expected to be in tension). Bentonite-enhanced seams are required for all BENTOMAT end-of-panel overlapped seams.

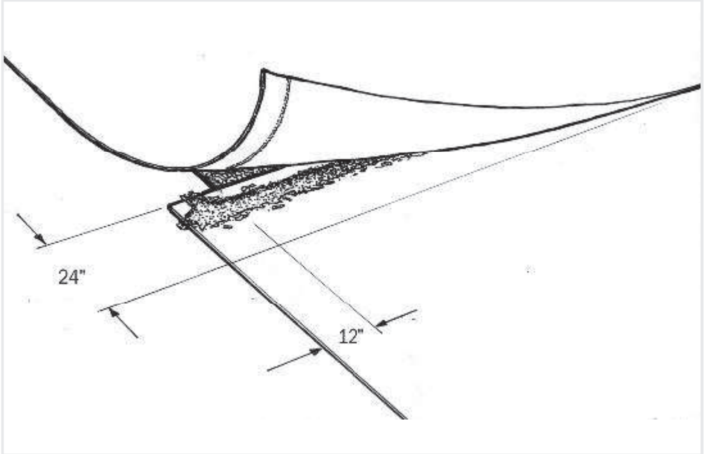
7.5

BENTOMAT end-of-panel, bentonite-enhanced, overlapped seams are constructed first by overlapping the adjacent panels, exposing the underlying panel, and then applying a continuous bead or fillet of granular sodium bentonite 12” from the edge of the underlying panel (Figure 11). The minimum application rate at which the bentonite is applied is one-quarter pound per linear foot (0.4 kg/m).

7.6

If longitudinal bentonite enhanced seams are required for BENTOMAT 200R, BENTOMAT ST, BENTOMAT DN, or BENTOMAT SDN, they are constructed by overlapping the adjacent panels a minimum 6 inches (150 mm), exposing the underlying edge, and applying a continuous bead of granular bentonite approximately 3 inches (75 mm) from the edge. For pond applications involving BENTOMAT CL or BENTOMAT CLT, longitudinal seams are constructed by overlapping adjacent panels by 12 inches (300 mm), exposing the underlying edge, and applying a continuous bead of bentonite approximately 6 inches (150 mm) from the edge. The minimum application rate for the granular bentonite is one quarter pound per linear foot (0.4 kg/m).

FIGURE 11
BENTOMAT END-OF-PANEL OVERLAPPED SEAM



SECTION 8

SEALING AROUND PENETRATIONS AND STRUCTURES

8.1

Cutting the GCL should be performed using a sharp utility knife. Frequent blade changes are recommended to avoid irregular tearing of the geotextile components of the GCL during the cutting process.

8.2

The GCL should be sealed around penetrations and structures embedded in the subgrade in accordance with Figures 12 through 14. Granular bentonite shall be used liberally (approximately 0.25 lbs/ln. ft. or 0.4 kg/m) to seal the GCL to these structures.

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FIGURE 12 A CROSS-SECTION OF A HORIZONTAL PIPE PENETRATION

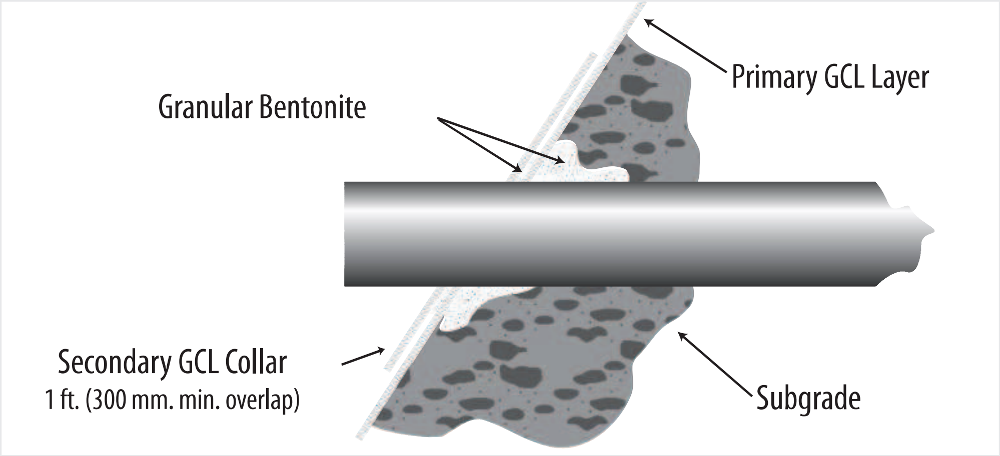


FIGURE 12 B ISOMETRIC VIEW OF A COMPLETED HORIZONTAL PIPE PENETRATION

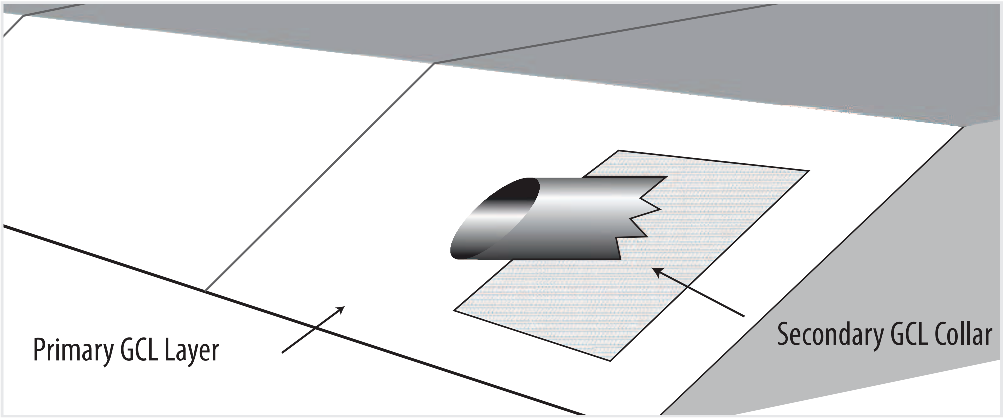


FIGURE 13 A CROSS-SECTION OF A VERTICAL PENETRATION

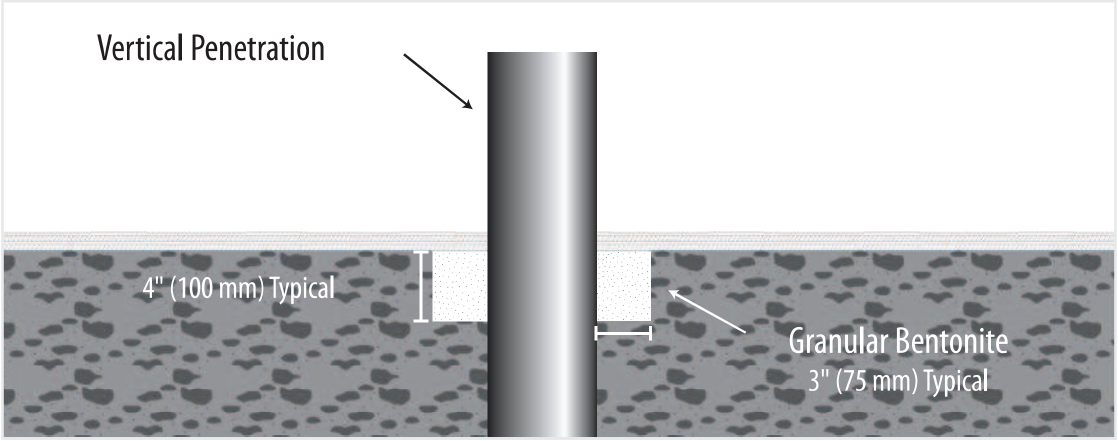


FIGURE 13B ISOMETRIC VIEW OF THE COMPLETED VERTICAL PENETRATION

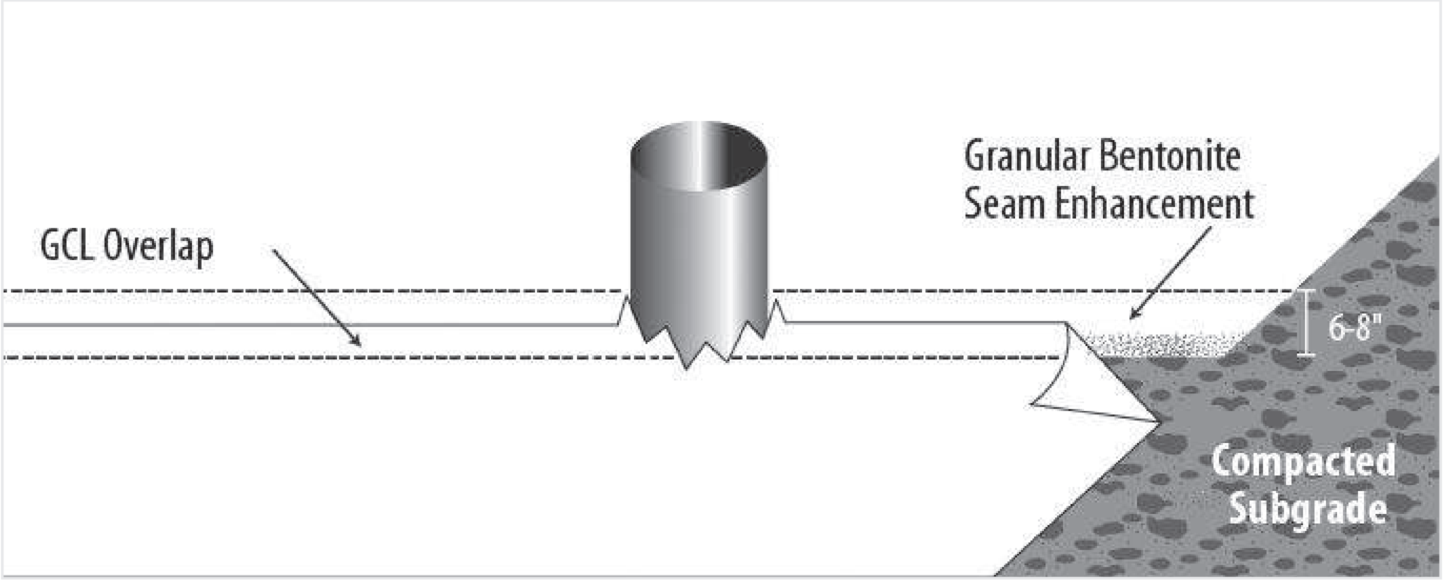
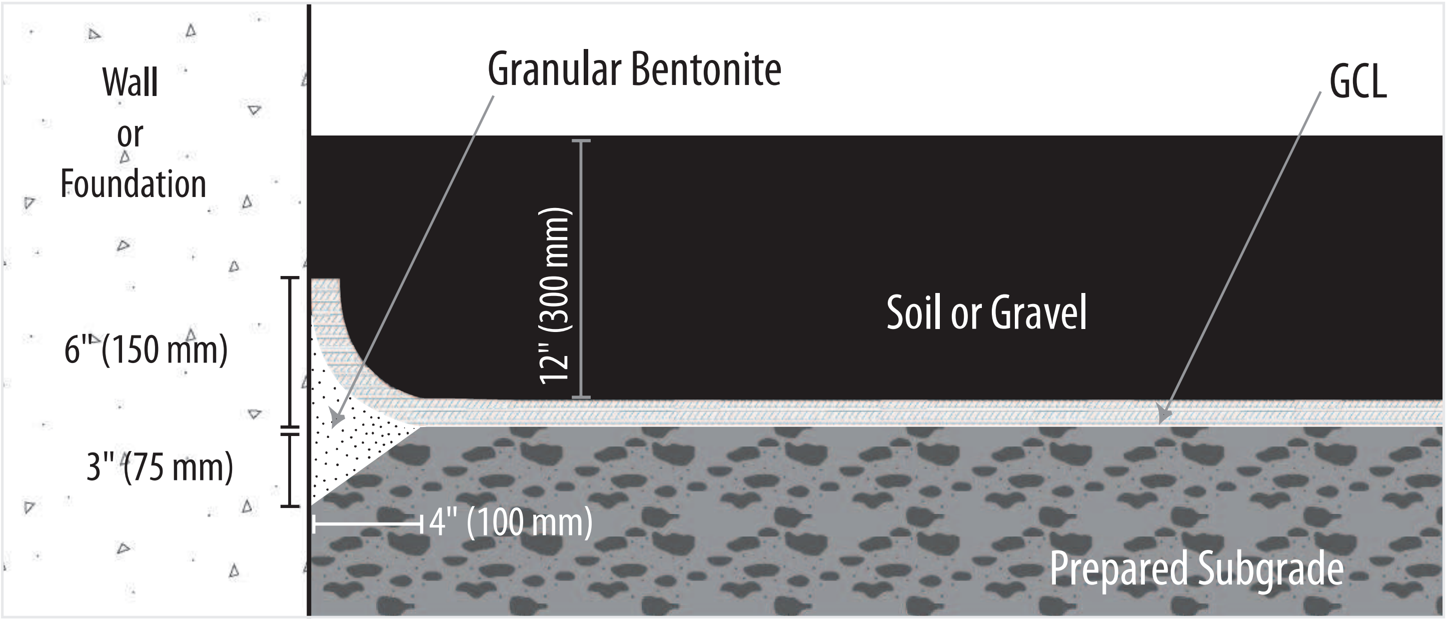


FIGURE 14 CROSS-SECTION OF GCL SEAL AGAINST AN EMBEDDED STRUCTURE OR WALL



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8.3
When the GCL is placed over a horizontal pipe penetration, a “notch” should be excavated into the subgrade around the penetration (Figure 12a). The notch should then be backfilled with granular bentonite. A secondary collar of GCL should be placed around the penetration, as shown in Figure 12b. It is helpful to first trace an outline of the penetration on the GCL and then cut a “star” pattern in the collar to enhance the collar’s fit to the penetration. Granular bentonite should be applied between the primary GCL layer and the secondary GCL collar.

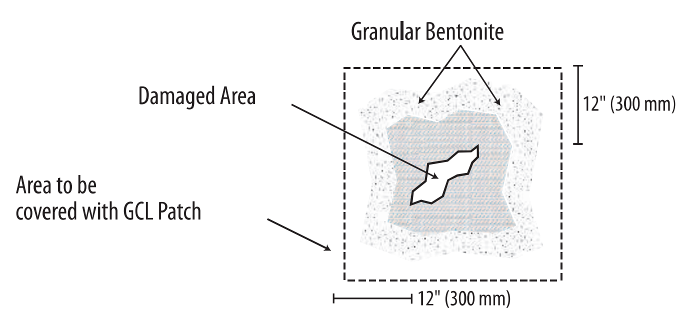
8.4
Vertical penetrations are prepared by notching into the subgrade as shown in Figure 13a. The penetration can be completed with two separate pieces of GCL as shown in Figure 13b. Alternatively, a secondary collar can be placed as shown in Figure 12a or 12b.

8.5
When the GCL is terminated at a structure or wall that is embedded into the subgrade on the floor of the containment area, the subgrade should be notched, as described in Sections 8.3 and 8.4. The notch is filled with granular bentonite; the GCL should be placed over the notch and up against the structure (Figure 14). Connection to the structure can be accomplished by placement of soil or stone backfill in this area. When structures or walls are at the top of a slope, additional detailing may be required. Contact CETCO for specific guidance.

SECTION 9
DAMAGE REPAIR

9.1
If the GCL is damaged (torn, punctured, perforated, etc.) during installation, it may be possible to repair it by cutting a patch to fit over the damaged area (Figure 15). The patch should be cut to size such that a minimum overlap of 12 inches (300 mm) is achieved around all parts of the damaged area. Granular bentonite should be applied around the damaged area prior to placement of the patch. It may be necessary to use an adhesive such as wood glue to affix the patch in place so that it is not displaced during cover placement. Smaller patches may be tucked under the damaged area to prevent patch movement.

FIGURE 15 DAMAGE REPAIR BY PATCHING



SECTION 10
COVER PLACEMENT

10.1
The final thickness of soil cover on the GCL varies with the application. A minimum cover layer must be at least 1 foot (300 mm) thick to provide confining stress to the GCL, eliminate the potential for seam separation and prevent damage by equipment, erosion, etc.

10.2
Cover soils should be free of angular stones or other foreign matter that could damage the GCL. Cover soils should be approved by the engineer with respect to particle size, uniformity, and chemical compatibility. Consult CETCO if cover soils have high concentrations of calcium (e.g. limestone, dolomite, gypsum, seashell fragments).

10.3
Recommended cover soils should have a particle size distribution ranging between fines and 1 inch (25 mm), unless a cushioning geotextile is specified.

10.4
Soil cover shall be placed over the GCL using construction equipment that minimizes stresses on the GCL. A minimum thickness of 1 foot (300 mm) of cover soil should be maintained between the equipment tires/tracks and the GCL at all times during the covering process. In high-traffic areas such as on roadways, a minimum thickness of 2 feet (600 mm) is required.

10.5

Soil cover should be placed in a manner that prevents the soil from entering the GCL overlap zones. Soil cover should be pushed up on slopes, not down slopes, to minimize tensile forces on the GCL.

10.6

When a textured geomembrane is installed over the GCL, a temporary geosynthetic covering known as a slip sheet or rub sheet should be used to minimize friction during placement and to allow the textured geomembranes to be more easily moved into its final position.

10.7

Cyclical wetting and drying of GCL covered only with geomembrane can cause overlap separation. Soil cover should be placed promptly whenever possible. Geomembranes should be covered with a white geotextile and/or operations layer without delay to minimize the intensity of wet-dry cycling. If there is the potential for unconfined cyclic wetting and drying over an extended period of time, the longitudinal seam overlaps should be increased based on the project engineer's recommendation.

10.8

To avoid seam separation, the GCL should not be put in excessive tension by the weight or movement of textured geomembrane on steep slopes. If there is the potential for unconfined geomembrane expansion and contraction over an extended period of time, the longitudinal seam overlaps should be increased based upon the project engineer's recommendation.

SECTION 11
HYDRATION

11.1

Hydration is usually accomplished by natural rainfall and/or absorption of moisture from soil. However, in cases where the containment of non-aqueous liquid is required, it may be necessary to hydrate the covered GCL with water prior to use.

11.2

If manual hydration is necessary, water can be introduced by flooding the covered lined area or using a sprinkler system. If flooding, care must be taken to diffuse the energy of the water discharge so that the cover material is not displaced.

11.3

If the GCL is hydrated when no confining stress is present, it may be necessary to remove and replace the hydrated material.

As discussed in Section 5.8, in many instances a needlepunch reinforced GCL may not require removal/replacement if the following are true:

- ► The geotextiles have not been separated, torn or otherwise damaged
- ► There is no evidence that the needlepunching between the two geotextiles has been compromised
- ► The GCL does not leave deep indentations when stepped upon
- ► Any overlapped seams with bentonite enhancement (see Section 7) are intact

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GEOSYNTHETIC CLAY LINERS

CETCO®

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AMCOL® INTERNATIONAL HEADQUARTERS

Headquartered in Hoffman Estates, IL, AMCOL International Corporation (AMCOL) operates over 68 facilities in Africa, Asia, Australia, Europe, North America and South America. AMCOL employs more than 1,750 employees in 26 countries. The company, established in 1927, currently trades on the New York Stock Exchange under the symbol "ACO". AMCOL produces and markets a wide range of specialty mineral products used for industrial, environmental and consumer-related applications. With more than 68 world-wide locations, AMCOL manages a global supply chain to deliver world-class quality. Our full range of products and services allow us to bring value to our customers, but ultimately, our commitment to understanding customer's needs is what sets us apart in our industry.

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