Trow

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Reference: OTGE00019054B

October 27, 2008

Mr. Babish Roy
CGS Projects – GN
P.O. Box 379
Pond Inlet, NU X0A 0S0

Via Facsimile:
(867) 899-7328

Response to BGC Letter of September 5, 2008
Geotechnical Investigation
Arctic Bay Sewage Lagoon
Arctic Bay, Nunavut

Dear Mr. Roy:

We acknowledge receipt of BGC Engineering Inc's letter reference 0308-006-01 dated September 5, 2008 providing a review of the geotechnical investigation at the above site. Our response to their letter is as follows:

Talik Consideration

A review of the aerial photograph base map as well as discussions were held with Trow personnel who visited the site was undertaken. Information obtained indicates that a stream was not observed on the site. The area under consideration is a low lying wet area which may act as an ephemeral stream during spring run off. However, because of very short duration of the flow of run off, the area re-freezes. To get a talik under a stream channel, we need essentially year around flow. Therefore the presence of a true talik under the ephemeral stream is considered to be of low likelihood.

It is noted that a pond is located in the middle of the proposed sewage lagoon. The depth of the pond was estimated to be in the order of 1.5 m. A borehole drilled immediately southeast of the pond (Borehole 8) encountered bedrock at 3.7 m depth. A borehole drilled northwest of the pond (Borehole 9) was terminated at 3.7 m depth. However, it is considered likely that the bedrock in this area is also present at relatively shallow depth i.e. 4 m to 4.5 m. It is noted that a talik will form within the lagoon basin. However, it will be confined by the bedrock at the bottom and by a large frozen zone all around which will provide containment. The lagoon berm will likely be constructed on top of the ephemeral stream. The ephemeral stream will likely freeze back as per the temperature contours provided in the geotechnical report. The presence of fill over the stream will insulate it from the warming effects of the temperature and the berm will also block any surface flow. This will cause any unfrozen layer to freeze in, at least under the downstream section of the berm.

Air Temperature

BGC has commented that the lagoon being at a lower elevation than the Nanasivik Airport will be warmer. A review of the climatic data suggests that the mean annual air temperature is likely controlled more by latitude than elevation. For example, Nanisivik and Pond Inlet have similar latitudes (72.8°) and MAAT of about 15.1°C but the elevations are 642 m and 55.2 m respectively. Igloolik has a latitude of 69.2° and a MAAT of 13.3°C and on Elevation of 21.3 m. Fire Fox (Old Dewline site) has a latitude of about 67.5°, MAAT of -11.8°C and an elevation of 584.4 m.

Thaw Settlements

Geotechnical analysis undertaken by NCI indicates that the soil under the inside toe of the berm will thaw to a depth of 0.5 m approximately and under the outside toe of the berm to 1.0 m depth approximately in the first year subsequent to construction of the berm. Thaw settlement of the toes of the berm were estimated based on Figure 3-32 presented in the Cold Regions Utility Memogram "Characteristic Thaw Stream Relationship in undisturbed Frozen Soils". A unit weight of 1750 kg/m^3 was assumed for the surficial on-site silty sand soils. Thaw stain for this soil was determined to vary between 3 percent to 6 percent. On this basis, the settlements of the inside and outside toes of the berm were estimated to be in the order of 15 mm to 30 mm and 30 mm to 60 mm respectively.

Geotechnical analysis also revealed that the maximum thaw after 20 years with disturbed soil conditions would extend to 4.5 m depth approximately at the inside toe of the berm and to 1.5 m depth approximately at the outside toe of the berm. The estimated settlements of the inside and outside toes of the berms vary from 135 mm to 270 mm and 45 mm to 90 mm respectively.

It is recommended that the settlements of the inside and outside toes of the berm should be monitored. It is noted that some maintenance of the berms may be required.

Slope Stability Analysis

The reviewer has commented that the berm width is 4 m and not 5 m and that the soil stragraphy slopes at 1 percent instead of being horizontal. In order to assess the affects of these changes on stability of the berm slopes, the downstream slope of the berm at Section AA was analysed for a 4 m wide crest width and soil stratigraphy sloping at 1 percent. The results (Figures 1 and 2) indicate factor of safety of 1.503 for the static case and 1.32 for the dynamic case. The factors of safety obtained for 5 m wide berm and horizontal soil stratigraphy were 1.54 and 1.35 respectively. It is therefore concluded that these changes do not significantly affect the computation of factors of safety.

The reviewer also commented that the cohesion of the ice used in the slope stability analysis may be high. Attached herewith is Figure 3-46 Long Term Cohesion of Frozen Soils (Weaver and Morganstorm, 1981) from Cold Regions Utilities Memogram. It indicates that the cohesion of the ice varies from approximately 90 kPa at 0°C to 340 kPa at -5°C. The cohesion value of ice used by Trow in the slope stability analysis was 100 kPa. Considering the concern expressed by the reviewer that the layer of ice is located close to the bottom of the active layer, it is possible that the temperature of the ice in the upper levels may rise to 0°C. Therefore, long term cohesion of ice of 90 kPa would be more appropriate.

In order to assess the influence of the lower cohesion of ice on the slope stability, long term cohesion of ice of 50 kPa was assumed. Circular slip surface analysis was undertaken for upstream slope of Section AA. The results of the analysis have been provided on Figures 3 and 4. The factors of safety obtained are the same as those obtained when using a cohesion of 100 kPa of the ice. These computations indicate that in a circular slip surface analysis, the cohesion value of ice has very little influence on the factor of safety of the slope.

The reviewer had also commented that the critical failure surface may be at the interface of the overlying sand to gravelly sand and the layer of ice. In order to investigate this possibility, non circular slip surface analyses were performed. The cohesion of ice was assumed to be 50 kPa. The crest width was taken as 4 m with sloping stratigraphy.

A total of 8 non-circular slip surfaces were analysed for the most critical cases and have been summarized on Table I.

Section	Slope Identification	Slope Inclination	Loading Conditions	Computed Factor of Safety	Figure #
A-A	Upstream Slope	3H:1V	Lagoon drained. Water level in berms at Elevation 99.0 m	2.35	5
			Lagoon drained. Water level in berm at Elevation 99.0 m with seismic loading	1.97	6
	Downstream Slope	3H:1V	Steady state seepage	2.40	7
			Steady state seepage with seismic loading	2.0	8
B-B	Upstream Slope	3H:1V	Lagoon drained. Water level in berms at Elevation 99.0 m	4.1	9
			Lagoon drained. Water level in berms at Elevation 99.0 m with seismic loading.	3.12	10
	Downstream Slope		Steady state seepage	4.3	11
			Steady state seepage with seismic loading	3.65	12

A review of the above table indicates that factor of safety of 2.35 to 4.1 would be available for the static loading conditions and 1.97 to 3.65 for seismic loading conditions. These factors of safety are higher than computed for the corresponding cases assuming circular slip surface failures. It is therefore concluded that potential failure at the interface of the overburden and ice layer is not the critical failure.

We trust that the information contained in this letter will be satisfactory for your purposes. Should you have any questions, please do not hesitate to contact this office.

Yours truly,

Trow Associates Inc.

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Geotechnical & Materials Engineering Services

Thaw Consolidation. The theory and modelling of the thaw-consolidation condition are presented for single and multiple layered soils by Morgenstern and Nixon (1971) and Nixon (1973). This theory combined a model of the heat conduction problem, defining the movement of the thaw plane, with the conventional relationships of porewater drainage from a thawed material under stress. This theory demonstrates the potential for generating excess pore pressures when the rate of thaw exceeds the rate of drainage, which can have adverse affects on bearing capacity and slope stability. Morgenstern and Nixon (1971) define a thaw consolidation ratio, "R", as a measure of the relative rates of generation and drainage of excess pore fluids. Conditions presenting an R parameter greater than unity would suggest danger of generating substantial pore pressures at the thaw plane, and the subsequent possibility of instability (Morgenstern and Nixon, 1971).

Laboratory testing of thaw consolidation requires much more control and apparatus than simple total thaw-settlement tests. Laboratory thaw-consolidation tests must measure the rate of thaw and the rate and volume of pore water ejected from the sample under a given load, and the resultant settlement as the sample is thawed in a controlled one-dimensional setting. Thaw-consolidation test apparatus and procedures are presented in Nixon and Morgenstern (1974).

Usually, permeable, coarse-grained soils consolidate (and the settlement takes place) in direct relationship to the advance of the thaw plane. Fine-grained soils, however, show only a limited amount of consolidation while thawing, and large pore pressures build up because of low permeability. An example of a major arctic project that required the application of thaw consolidation was the design for

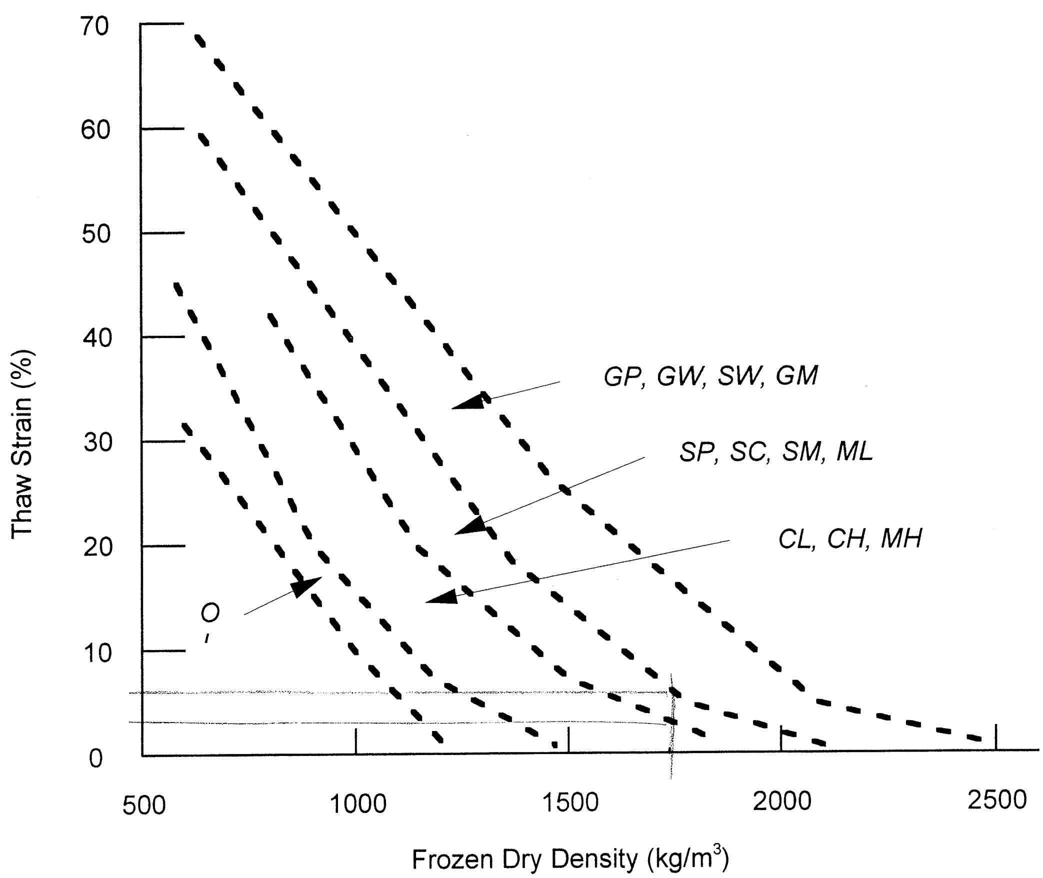


FIGURE 3-32 CHARACTERISTIC THAW STRAIN RELATIONSHIPS IN UNDISTURBED FROZEN SOILS (after Hanna et al., 1983; Nelson et al., 1983)

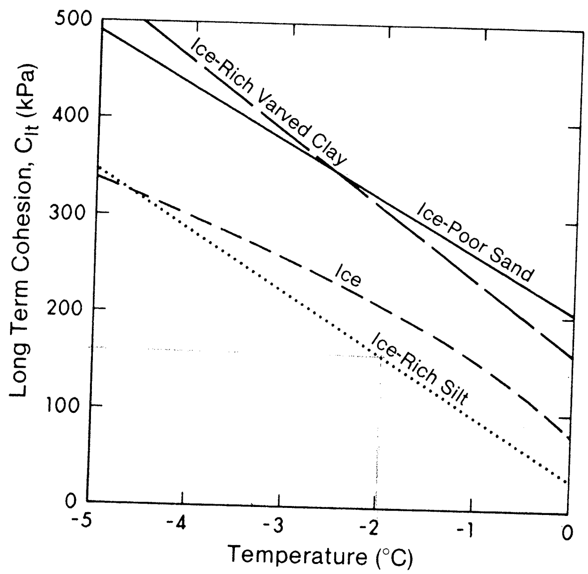


FIGURE 3-46 LONG-TERM COHESION OF FROZEN SOILS (Weaver and Morgenstern, 1981)

Crory (1963; 1982), Nixon and McRoberts (1976), Nottingham and Christopherson (1983), Weaver and Morgenstern (1981), Neukirchner (1985) and Nixon (1988). Figure 3-45 illustrates a schematic flow chart for designing piles in permafrost as a function of bearing material, ground temperature, and soil ice conditions. In general, piles should be designed based on the lesser of long-term adfreeze strength, or creep settlement limits. The long-term adfreeze strength (t_{lt}) can be estimated as:

$t_{lt} = m \cdot c_{lt}$

where:

m = the pile material roughness coefficient:

= 0.6 for steel and concrete

= 0.7 for uncreosoted wood

= 1.0 for corrugated steel pipe (Weaver and Morgenstern, 1981)

c_{lt} = the long-term cohesion, kPa, of the frozen soil at the design ground temperature (Figure 3-46).

The creep settlements of piles in frozen soils is a function of the time, pile diameter, and soil type and temperature. Weaver and Morgenstern (1981) developed a series of equations for predicting allowable shear stress and pile capacity versus creep settlement. The equations for ice-rich soils were based on an established flow law model for steady-state (secondary) creep in polycrystalline ice. The equations for ice-poor soils were based on an established primary creep law model. The following general equations for predicting the load capacity of friction piles in ice-rich (P_{IR}) and ice-poor (P_{IP}) soils are based on the respective expanded forms presented in Weaver and Morgenstern (1981).

$$P_{IR} = 2\pi aL\left(\frac{u_a(n-1)}{atB3^{(n+1)/2}}\right)^{1/n}$$

$$P_{IP} = 2\pi aL\left(\frac{u_a(c-1)}{at^b 3^{(c+1)/2}}\right)^{1/c} w(\theta+1)^k$$

where:

a = pile radius, m

L = pile length in frozen soil, m

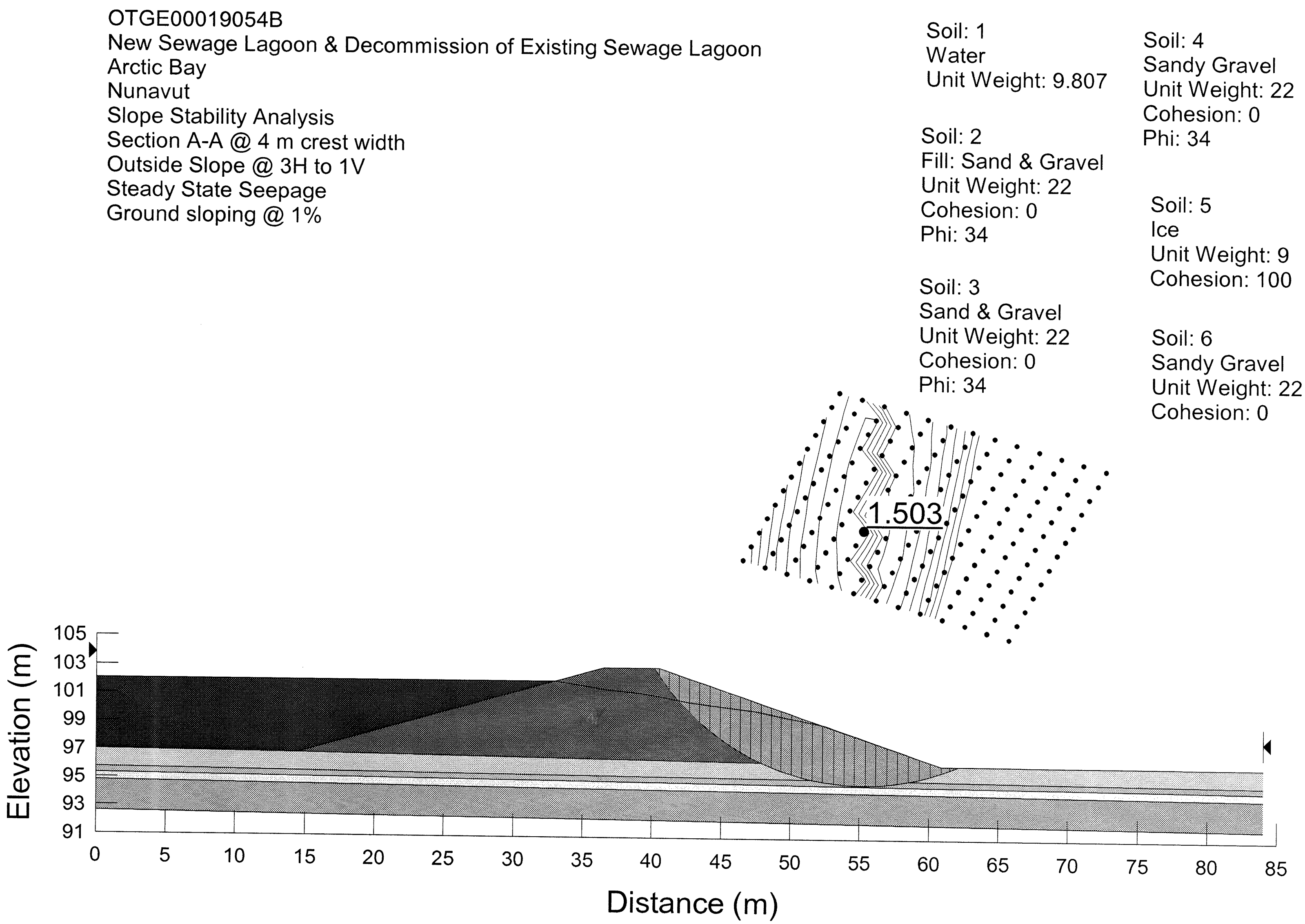
u = pile displacement/settlement, mm/hr

t = time, hr

n, B = secondary creep equation constants, B, kPa^{-n}/yr

c, b, w, k = primary creep equation constants, (w, $MPa \cdot hr^{b/c}/{}^{\circ}C^k$)

Figure 1



OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section A-A @ 4 m crest width
Outside Slope @ 3H to 1V
Steady State Seepage
Ground sloping @ 1%
Soil: 1
Water
Unit Weight: 9.807
Soil: 2
Fill: Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34
Soil: 3
Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34
Soil: 4
Sandy Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34
Soil: 5
Ice
Unit Weight: 9
Cohesion: 100
Soil: 6
Sandy Gravel
Unit Weight: 22
Cohesion: 0
1.503
Elevation (m)
105
103
101
99
97
95
93
91
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Distance (m)

Figure 2

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section A-A @ 4 m crest width
Outside Slope @ 3H to 1V
Steady State Seepage
Ground sloping @ 1%
Seismic = 0.05g

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 4
Sandy Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 5
Ice
Unit Weight: 9
Cohesion: 100

Soil: 6
Sandy Gravel
Unit Weight: 22
Cohesion: 0

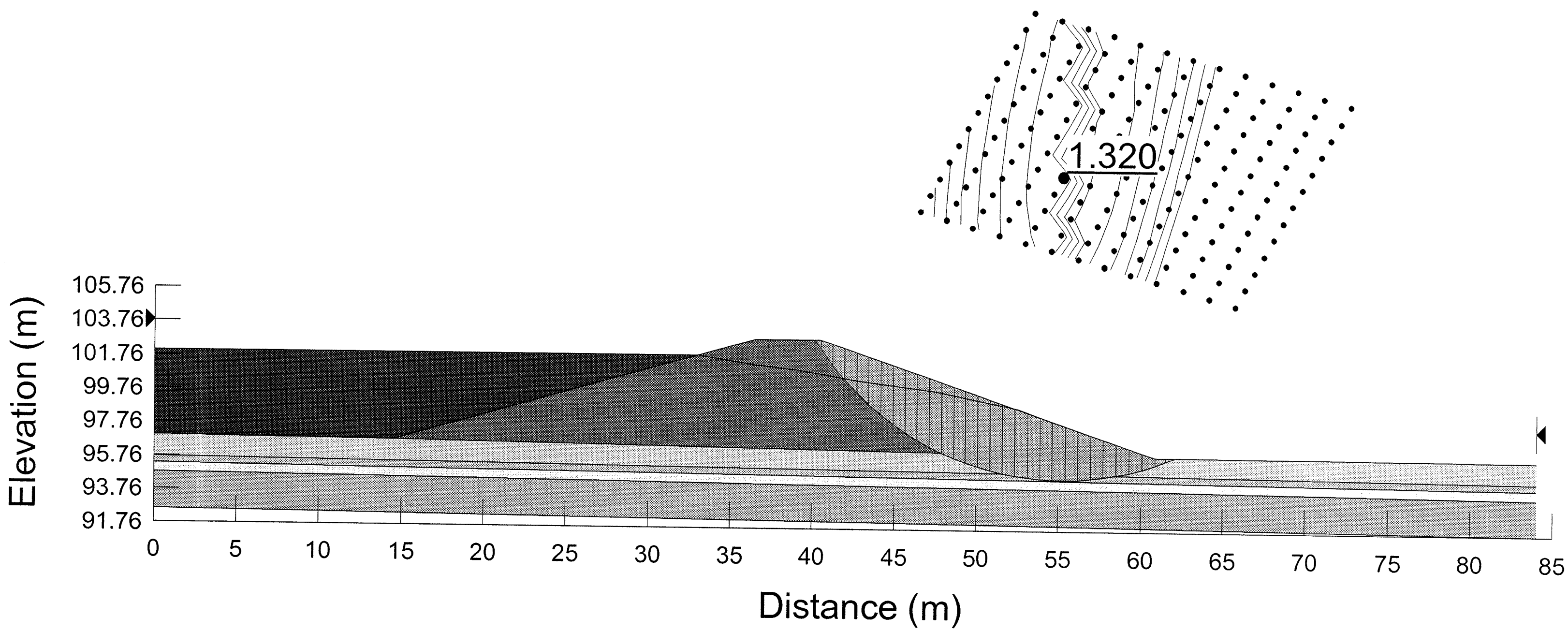


Figure 3

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section A-A @ 5 m crest width
Inner Slope @ 3.0H to 1V
Completely Submerged
Ice shear strength = 50 kPa

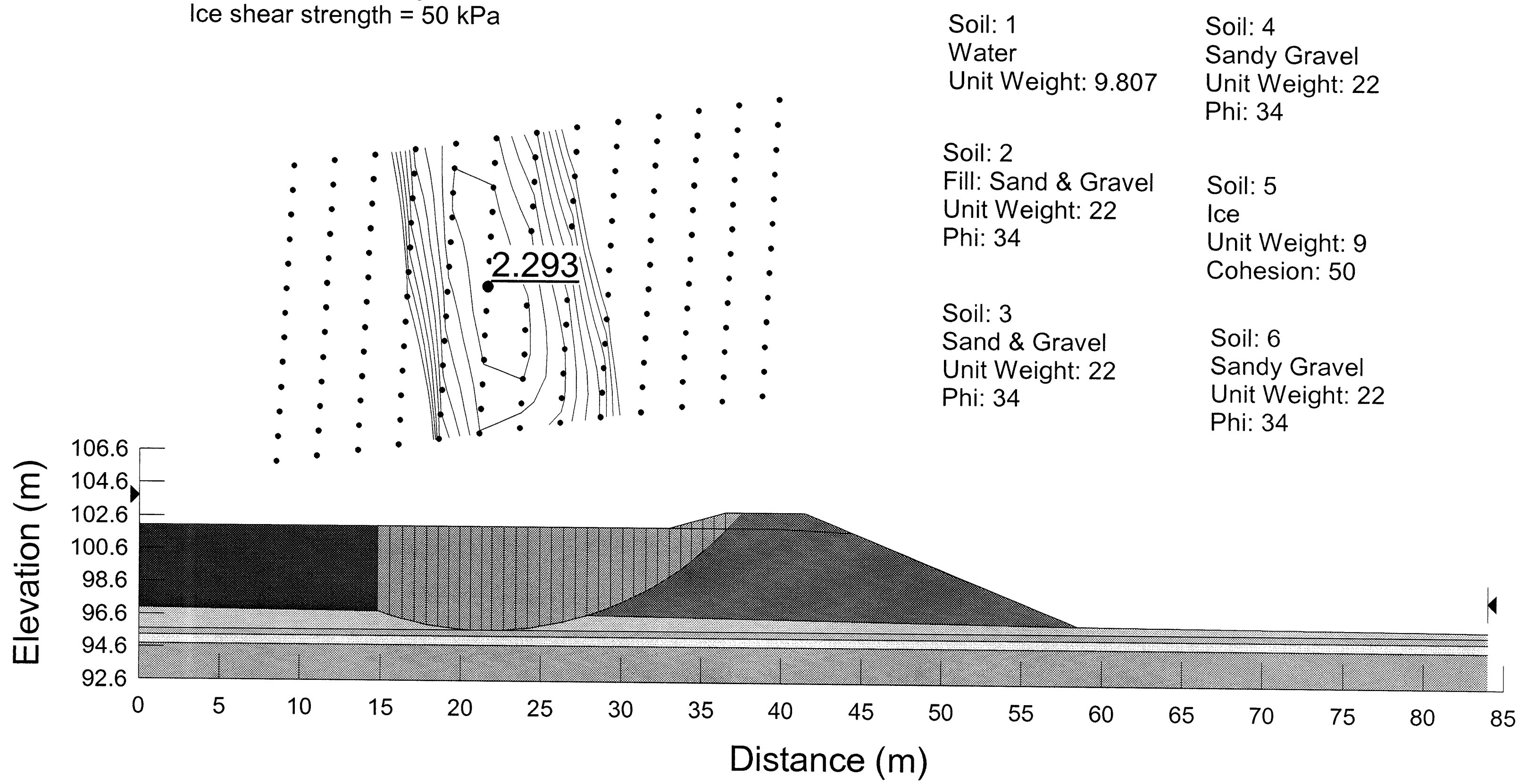


Figure 4

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section A-A @ 5 m crest width
Inner Slope @ 3.0H to 1V
Completely Submerged
Ice shear strength = 50 kPa

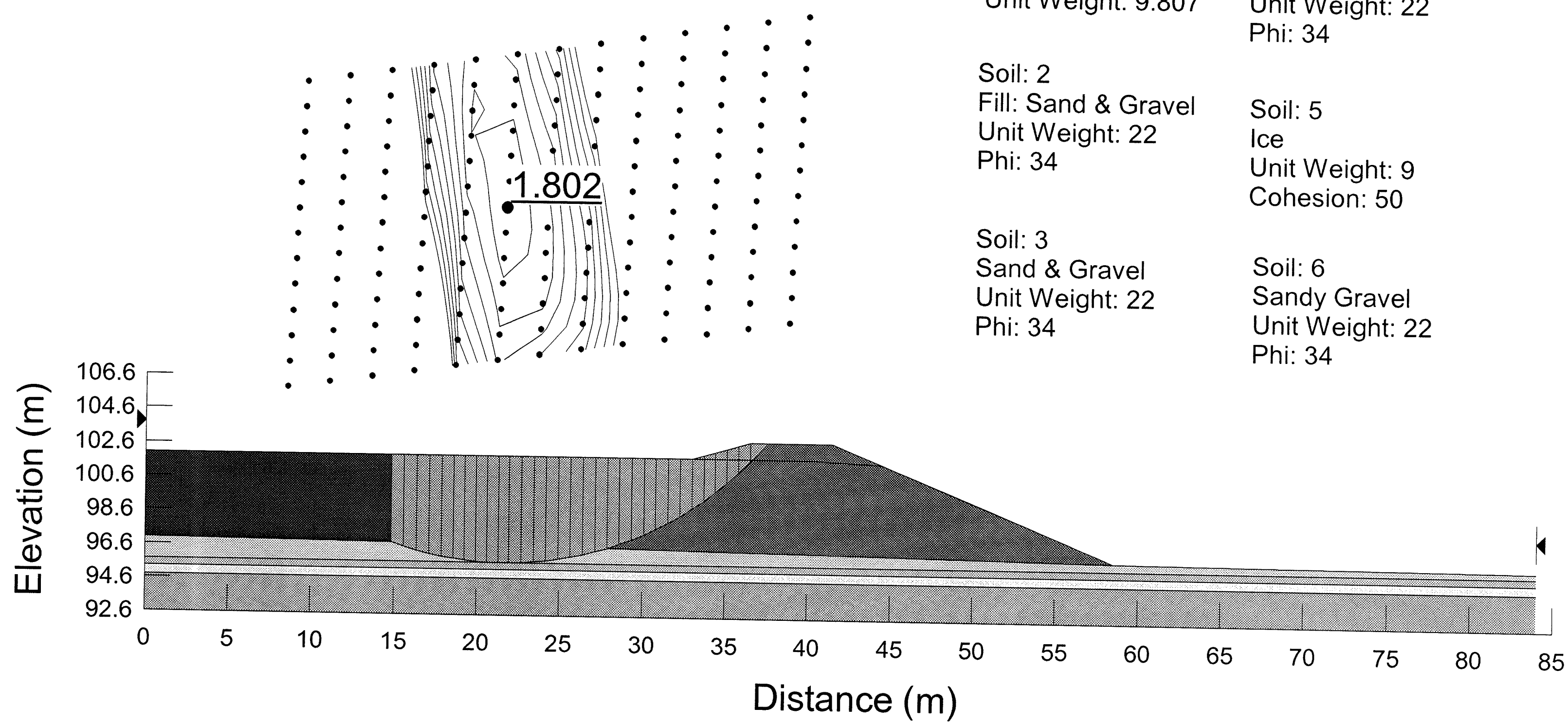


Figure 5

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section A-A @ 4 m crest width
Inner Slope @ 3.0H to 1V
Water in berm at 99.0 m, Lagoon Empty
Ground sloping @ 1%
Ice shear strength = 50 kPa
Non circular slip surface through the ice layer

Soil: 1
Fill: Sand & Gravel
Unit Weight: 22
Phi: 34

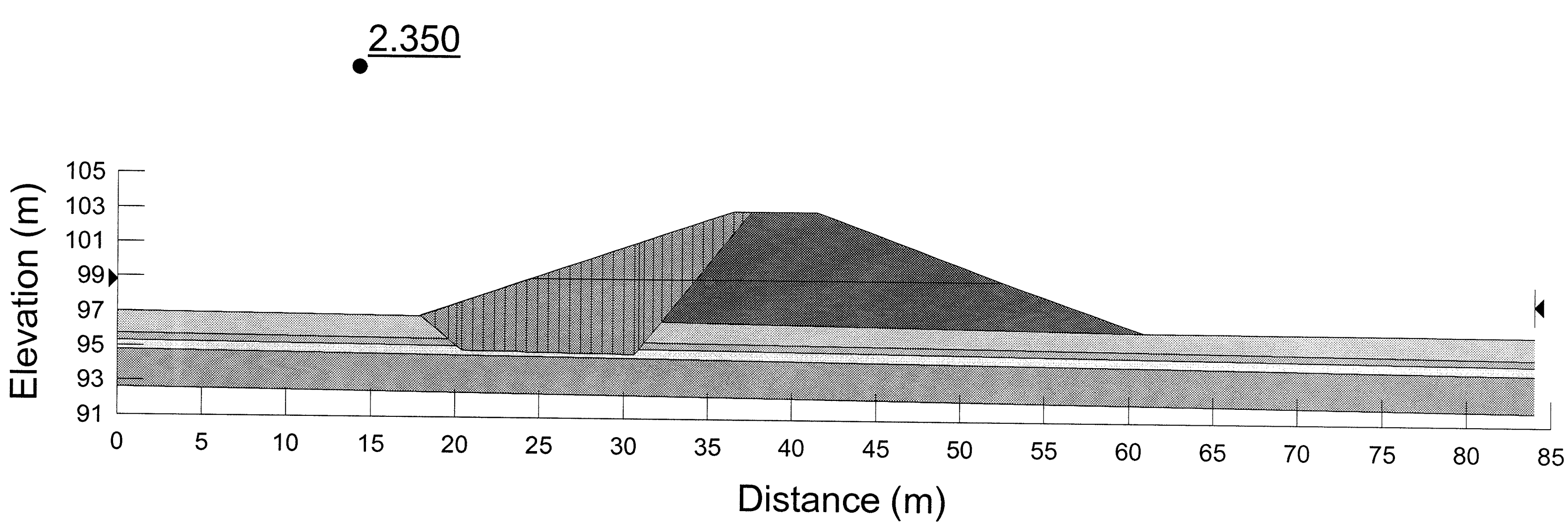
Soil: 2
Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Sandy Gravel
Unit Weight: 22
Phi: 34

Soil: 4
Ice
Unit Weight: 9
Cohesion: 50

Soil: 5
Sandy Gravel
Unit Weight: 22
Phi: 34

Soil: 6
Sandy Gravel
Unit Weight: 22
Phi: 34



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New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section A-A @ 4 m crest width
Inner Slope @ 3.0H to 1V
Water in berm at 99.0 m, Lagoon Empty
Ground sloping @ 1%
Ice shear strength = 50 kPa
Non circular slip surface through the ice layer
Seismic = 0.05g

Figure 6

Soil: 1
Fill: Sand & Gravel
Unit Weight: 22
Phi: 34

Soil: 2
Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Sandy Gravel
Unit Weight: 22
Phi: 34

Soil: 4
Ice
Unit Weight: 9
Cohesion: 50

Soil: 5
Sandy Gravel
Unit Weight: 22
Phi: 34

Soil: 6
Sandy Gravel
Unit Weight: 22
Phi: 34

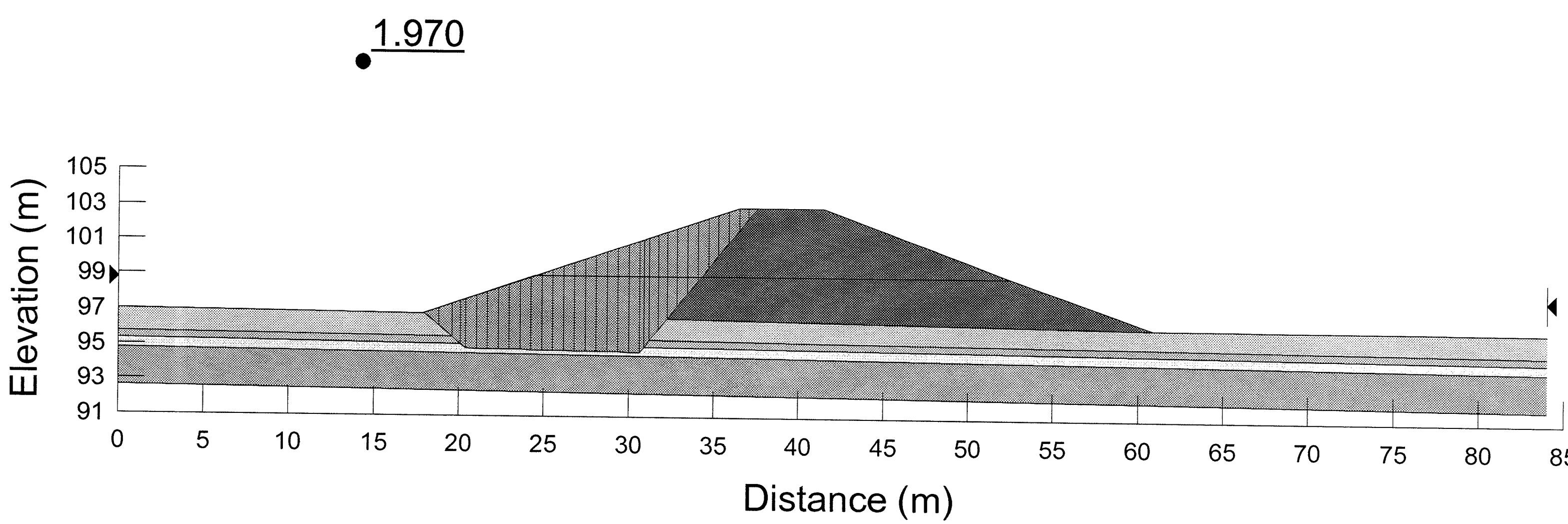

Figure 7

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section A-A @ 4 m crest width
Outside Slope @ 3H to 1V
Steady State Seepage
Ground sloping @ 1%
Ice shear strength = 50 kPa
Non circular slip surface through the ice layer

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 4
Sandy Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 5
Ice
Unit Weight: 9
Cohesion: 50

Soil: 6
Sandy Gravel
Unit Weight: 22
Cohesion: 0

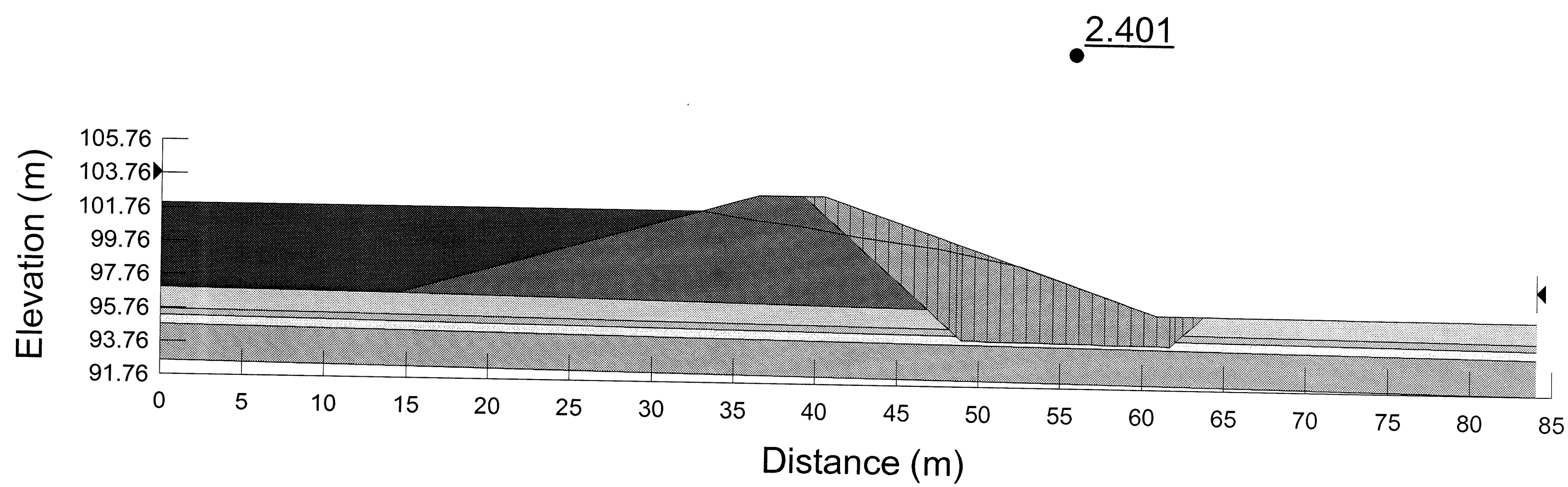

Figure 8

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section A-A @ 4 m crest width
Outside Slope @ 3H to 1V
Steady State Seepage
Ground sloping @ 1%
Ice shear strength = 50 kPa
Non circular slip surface through the ice layer
Seismic = 0.05g

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 4
Sandy Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 5
Ice
Unit Weight: 9
Cohesion: 50

Soil: 6
Sandy Gravel
Unit Weight: 22
Cohesion: 0

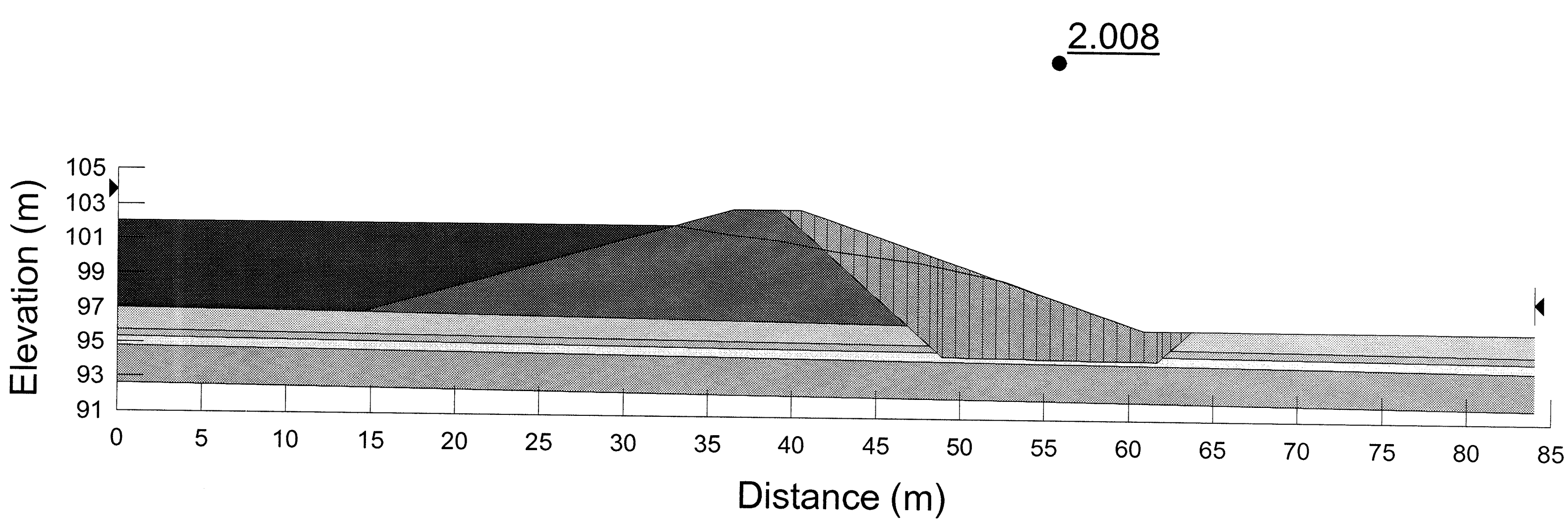

Figure 9

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section B-B @ 4 m crest width
Inner Slope @ 3H to 1V
Completely Submerged
Ground sloping @ 1%
Non circular slip surface through the ice layer

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Silty sand & gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 4
Ice
Unit Weight: 9
Cohesion: 50

Soil: 5
Sandy Gravel
Unit Weight: 22
Cohesion: 0

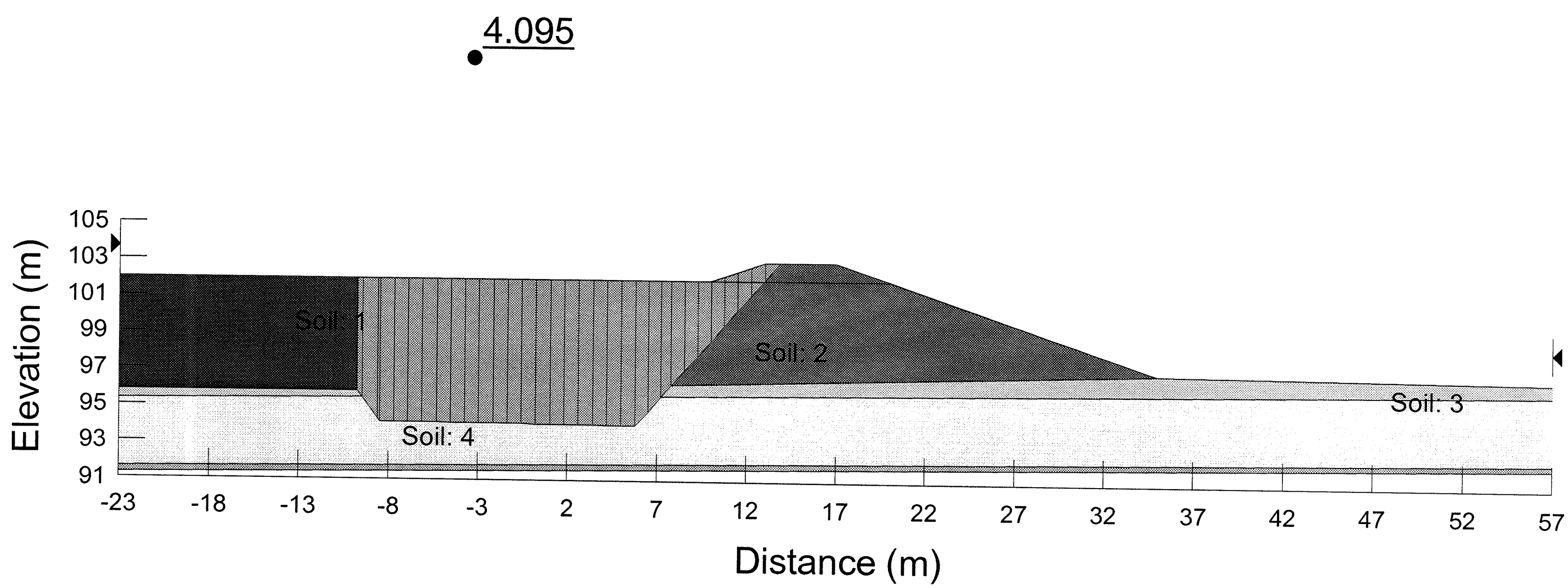

Figure 10

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section B-B @ 4m crest width
Inner Slope @ 3.0H to 1V
Completely Submerged
Ground sloping @ 1%
Non circular slip surface through the ice layer
Seismic = 0.05g

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Silty sand & gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 4
Ice
Unit Weight: 9
Cohesion: 50

Soil: 5
Sandy Gravel
Unit Weight: 22
Cohesion: 0

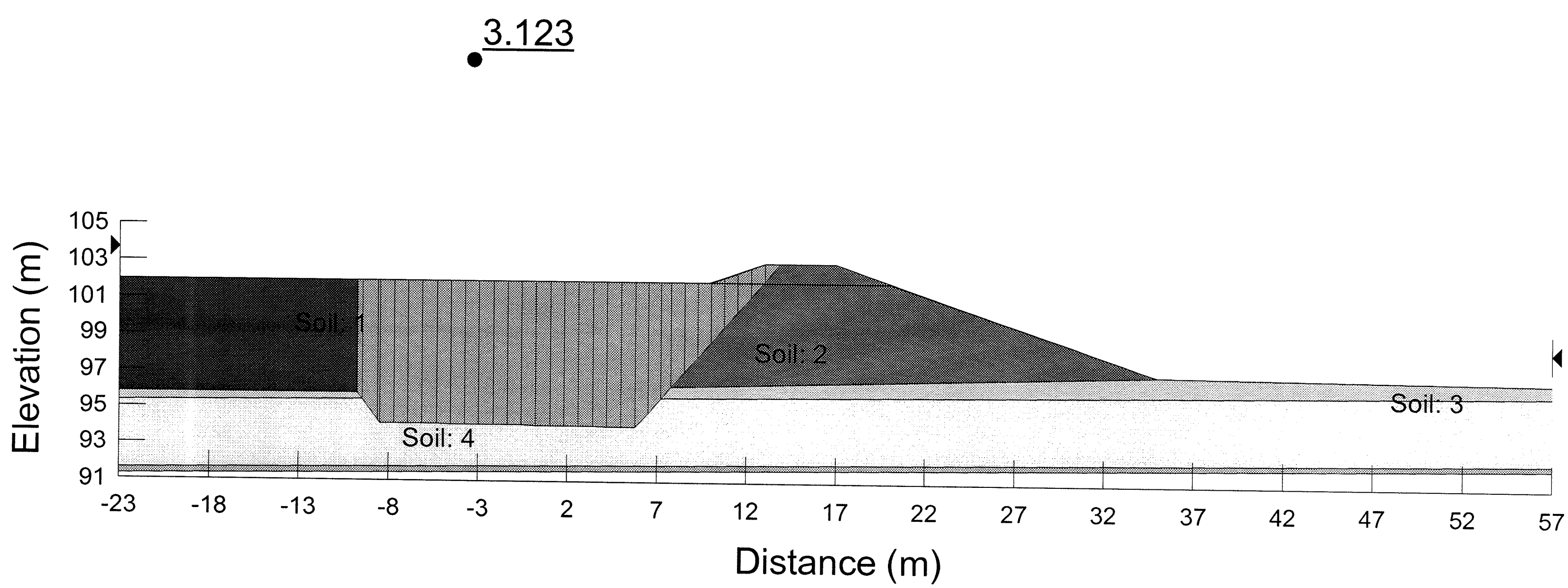

Figure 11

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section B-B @ 4 m crest width
Outside Slope @ 3H to 1V
Steady State Seepage
Non circular slip surface through the ice layer

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Silty sand & gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 4
Ice
Unit Weight: 9
Cohesion: 50

Soil: 5
Sandy Gravel
Unit Weight: 22
Cohesion: 0

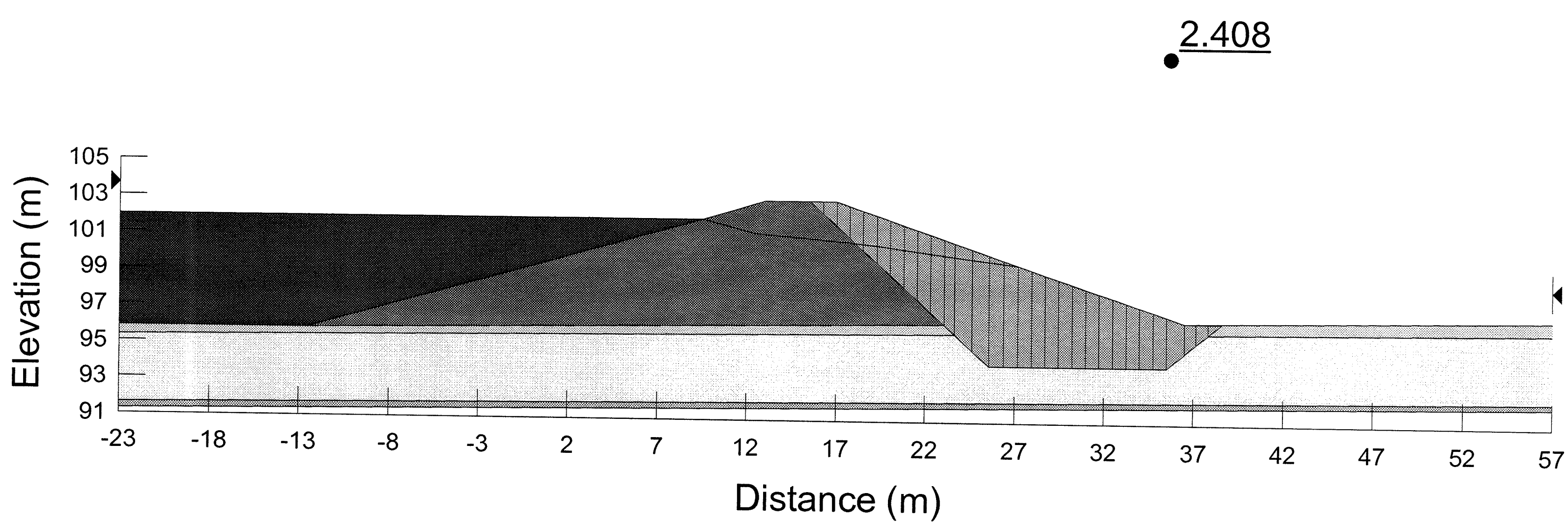

Figure 12

OTGE00019054B
New Sewage Lagoon & Decommission of Existing Sewage Lagoon
Arctic Bay
Nunavut
Slope Stability Analysis
Section B-B @ 4 m crest width
Outside Slope @ 3.0H to 1V
Steady State Seepage
Non circular slip surface through the ice layer
Seismic = 0.05g

Soil: 1
Water
Unit Weight: 9.807

Soil: 2
Fill: Sand & Gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 3
Silty sand & gravel
Unit Weight: 22
Cohesion: 0
Phi: 34

Soil: 4
Ice
Unit Weight: 9
Cohesion: 50

Soil: 5
Sandy Gravel
Unit Weight: 22
Cohesion: 0