Design of Dyke Realignment, Oxbow Dyke, Aulac, NB

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UNB EST. 1785 UNIVERSITY OF NEW BRUNSWICK — Engineering Design Symposium

VIRALTEC GEOSOLUTIONS

Project Overview

The coastal areas of New Brunswick (NB) and Nova Scotia (NS) are protected from flooding by a system of 80 km of earthen dykes. A new section of dyke has been proposed across the Beausejour Marsh in Aulac, NB. This dyke will protect the road and rail transportation corridors between NB and NS and local archeological sites from rising seawater levels due to climate change and post-glacial land subsidence. An estimated $5 million worth of economic impact between the provinces daily through the transportation corridors in the area. In addition to infrastructure protection the new dyke alignment with allow for salt marsh restoration.

Geology of the Area

The Aulac site is in an intertidal marsh deposit area. Based on borehole logs provided by NBDTI, the marshland deposit consists mainly of sandy silt transitioning to organic rich clay after a depth of about 2-4 m. A cross-section line of A-A' in Figure 1 can be found in Figure 4. The maximum depth of NBDTI boreholes is 9 m and no bedrock was encountered. It is estimated the bedrock is located at a depth greater than 25 m. Based on bedrock maps of NB the underlying bedrock is part of the Richibucto Formation. The occurrence of till found in Borehole 1 (BH1) is interpreted to be part of a drumlin or a recessional moraine formed during the last glaciation.

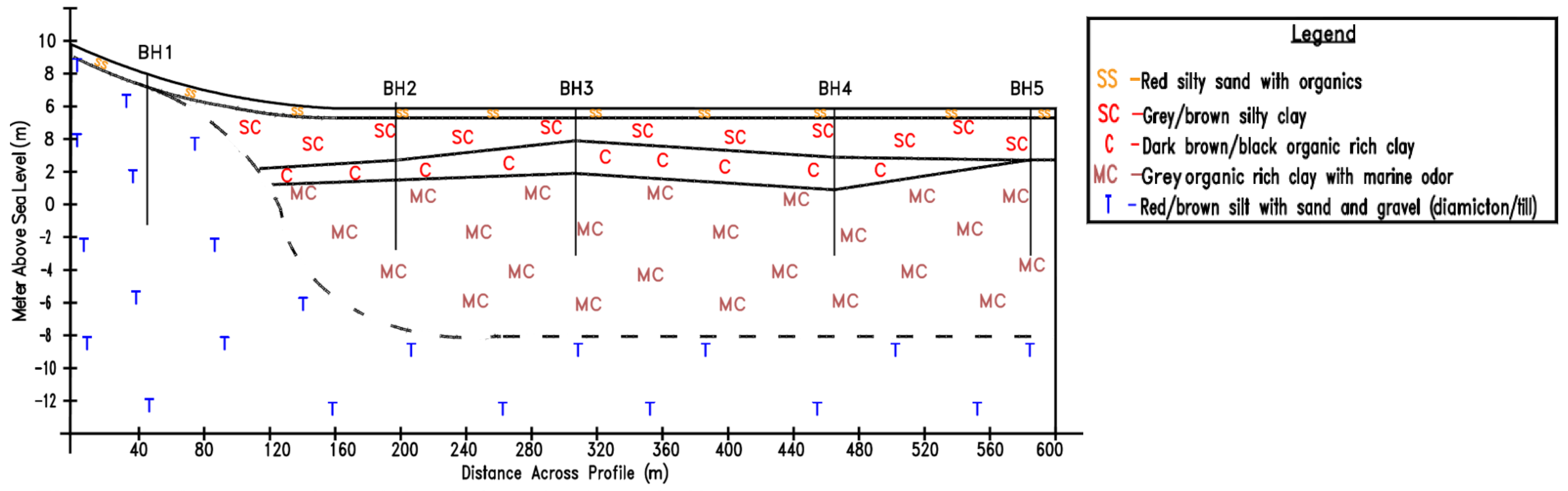

Figure 1: Cross section of the Aulac site from A-A'.

Geophysical Field Tests

Viraltec conducted an EM31-short survey to understand the subsurface conditions. Surface water electrical conductivities were collected to understand if variations in electrical conductivities were due to changes in soil texture or pore-water salinity. The software Surfer-16 was used to create a contour map of the subsurface electrical conductivities with surface water conductivities overlain shown in Figure 2. Variations in these conductivities were determined to be from changes in pore-water salinity not textural variations.

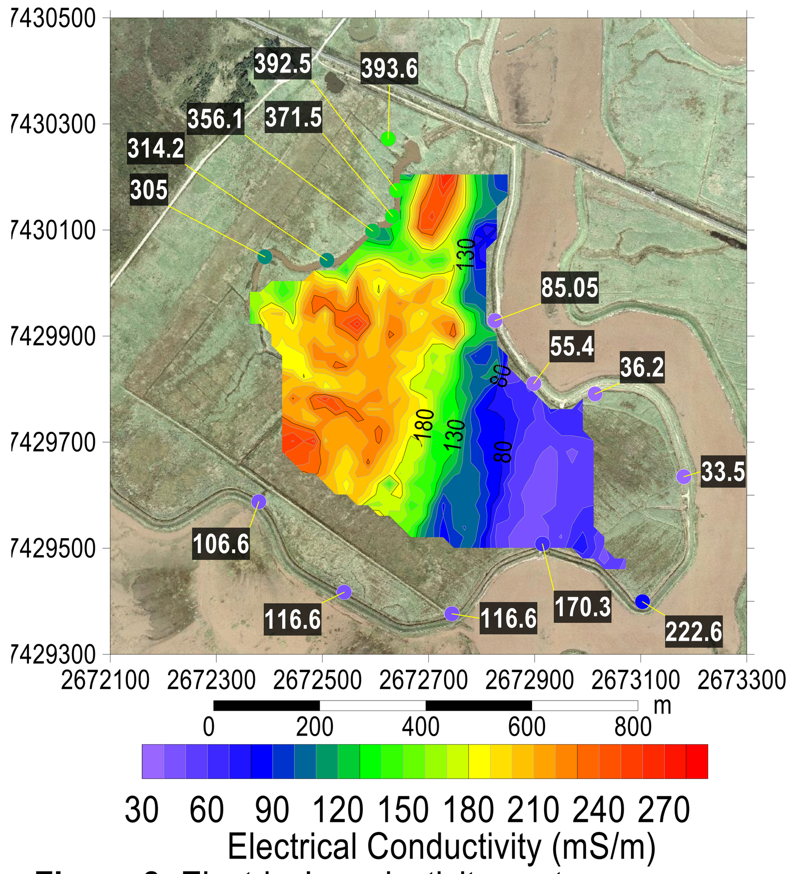

Figure 2: Electrical conductivity contour map.

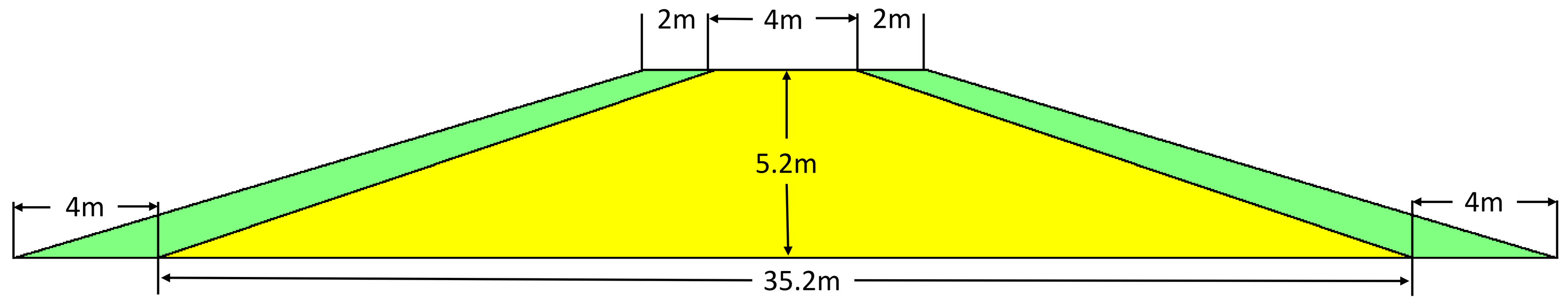

Figure 3: Alignment of Dyke with cross sectional line from A-A'.

Dyke Geometry

The alignment of the dyke was chosen based on the overlap on the existing dykes, the length and the proximity to the provincially significant wetland (PSW) zone. The final alignment can be seen in Figure 4. A crest elevation of 11.2 masl or a total height of 5.2 m is required to provide enough protection against the rising sea level. The side slope ratio is 3H:1V. Figure 3 shows the cross section of the dyke.

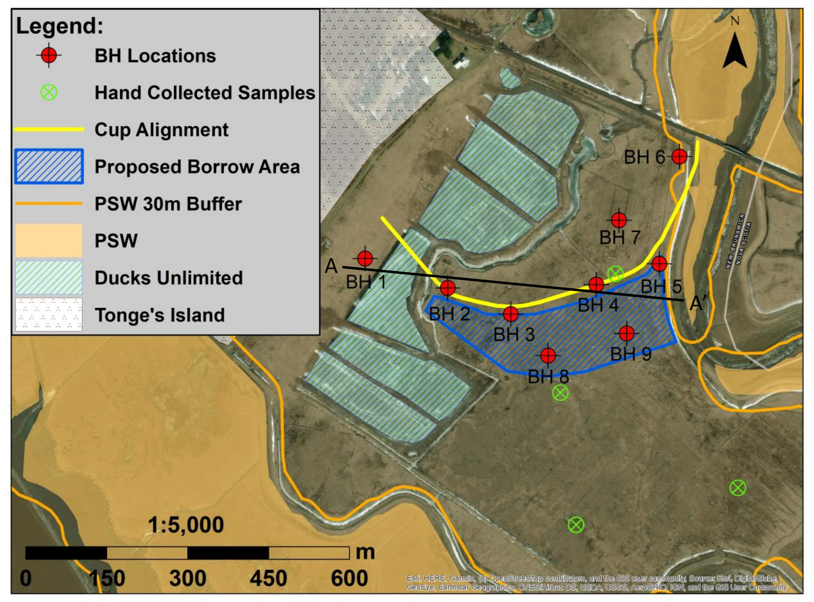

Figure 4: Alignment of Dyke with cross section line from A-A'.

Laboratory Tests

Viraltec obtained soil samples to conduct laboratory testing in the form of; Shelby tubes (NBDTI) and hand augured samples (direct collection by Viraltec). The parameters obtained were used in the analysis of the proposed dyke cross-sections. The test performed and the associated soil parameter determined is listed in Table 1.

Table 1: Summary of laboratory results and associated parameters determined.

Test	Parameters	Use	Results
Grain Analysis	Grain Size	Soil Classification	Homogeneous
Specific Gravity	G_s	Density of Soil	2.6 – 2.67
Atterberg limits	w_L, w_P, I_p	Soil Classification	CL or OL
Natural Moisture Content	w	Site characteristics	10 % - 40.5 %
Hydraulic Conductivity	K	Seepage Analysis	$2.6 \times 10^{-9} - 4.0 \times 10^{-10}$ m/s
Consolidation	C_c, C_v, K	Maximum Settlement	0.225, 3.871 m^3/year
Direct Shear	Φ', c'	Stability Analysis	23.70°
Compaction	OMC, MDD	Stability Analysis	15.5% , 1730 kg/m^3
UCS (Compacted)	C_u	Stability Analysis	109.98 kPa

Stability Analyses of Design (Part 1)

The dyke cross section was analyzed for overtopping, horizontal sliding, foundation bearing capacity and settlement. Factor of Safety (FS) along with other results are listed in Table 2 and the settlement curve shown in Figure 5.

Table 2: Summary of analyses results.

Scenario	Result
Horizontal Sliding	FS: 13.1
Overtopping	Rip rap on the landward facing slope is recommended
Bearing Capacity	Short –term FS: 3, Long –term FS: 24
Settlement (one-way drainage)	Primary: 550 mm, Secondary (1st year): 249 mm Total settlement (1st year): 298 mm

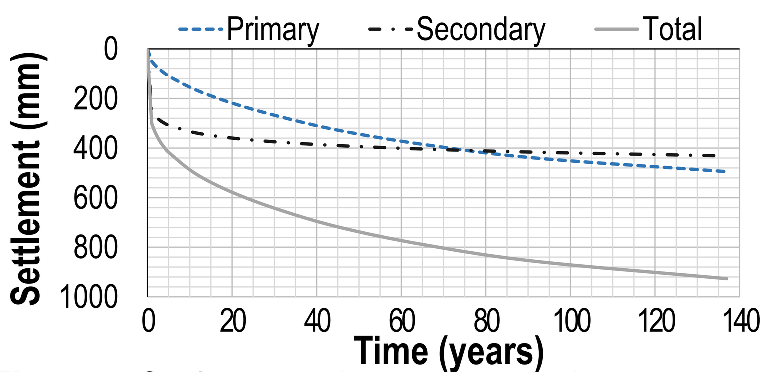

Figure 5: Settlement using one-way drainage.

Stability Analyses of Design (Part 2)

The minimum FS for the functional design of the dyke cross-section in the short-term and long-term scenarios was determined to be 1.5. The seepage analysis was completed assuming steady-state conditions. The slope stability analysis within GeoStudio was conducted using the Bishop method in which, the slip surfaces were identified using the Entry and Exit method.

A sensitivity analysis was conducted to determine how the FS changed based on variations in soil properties. The input parameters included a range of undrained cohesion (c_u) values from 8.3 - 33 kPa and a range of internal friction (φ°) values from 20°- 28°. It was found that the FS increases as the c_u and φ° values increase. This relationship is shown in Figure 6.

Option 1- Inclined piles, was created using the original parameters of the soil obtained through laboratory testing. Inclined piles were set to have a shear force of 500 kN applied parallel to the slip surface and an out-of-plane spacing of 1.5 m. The slope stability of the landward facing slope at a maximum water level of 11.2 masl with the inclined piles is shown in Figure 7.

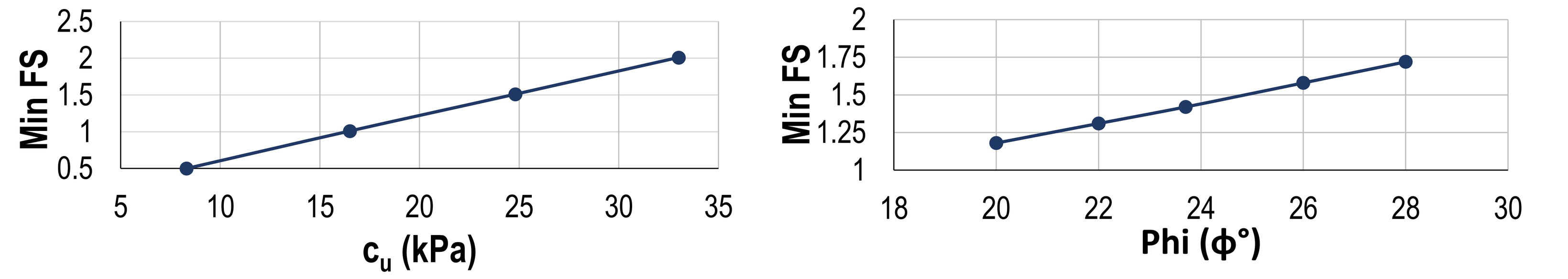

Figure 6: Plot of undrained cohesion, c_u (left) and the internal friction angle, φ° (right) increasing with a higher FS

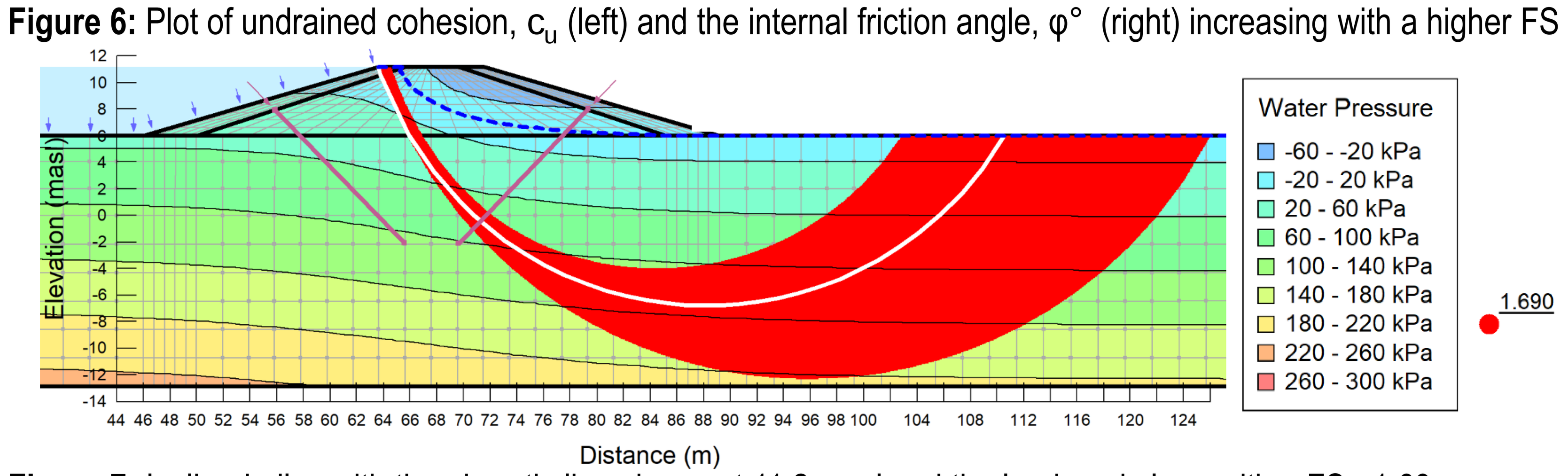

Figure 7: Inclined piles with the phreatic line shown at 11.2 masl and the landward slope with a FS= 1.69

Cost Analyses

Total construction cost of all evaluated alternatives are listed in Table 3. The wick drain spacing was designed off the assumption of one-way drainage with an impermeable layer at 25 m. At 24.8 kPa, a 50% increase from the original 16.15 kPa (as a result of wick drains), the design achieved the minimum FS required. Cost analysis was done for the total settlement of 927 mm to be achieved within 1-5 years. Figure 8 shows the cost analysis for the various wick drain spacings.

Table 3: Total cost for all alternatives.

Option	Design	Total Cost
1	Vertical Wood Pile	$ 6,621,000
2	Vertical Recycled Composite Piles	$ 5,128,000
3	Perpendicular Recycled Composite Piles	$ 4,746,000
4	Wick Drains (Triangular)	$ 2,798,000

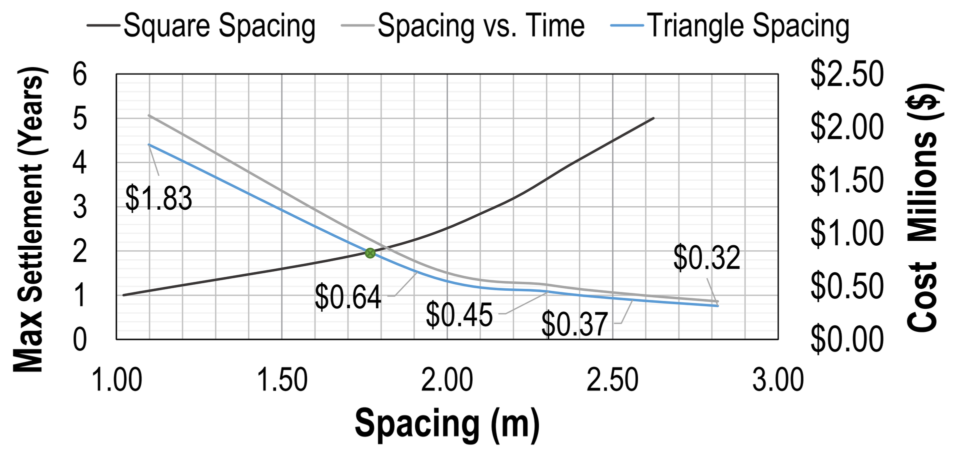

Figure 8: Wick drain design optimization.

Conclusions and Recommendations:

Archeological Studies:
- Geophysical magnetic survey using Fluxgate Magnetometer to find archeological remains
- Monitoring plan for the pre-construction and construction phases

Environmental Studies:
- Biodiversity study to determine affected species

Field and Laboratory Tests:
- Drill boreholes to bedrock or the significant depth of effective stresses, whichever is first
- Seismic investigation to assess for the depth to bedrock and interpret 2-way drainage

Dyke Design:
- In-depth aboiteaux design for drainage requirements
- Seepage analysis of the gravel trench from intruding oceanward flow
- Range of wick drain gravel blanket thickness explored in-depth
- Cost analysis of accelerated pumping system for wick drains

Monitoring programs:
- Height of dyke measurements
- Cover monitoring (rip rap: check for animal burrows and undesirable vegetation)
- Monitor accumulation of ice and for erosion
- Remote sensing methods (ex: Lidar) to determine the condition of the dyke structure.
- Sensors to indicate pore water pressure, temperature and inclination internally.
- Deformation FOS sensors to monitor mechanical stresses internally.

Acknowledgements:

Viraltec would like to acknowledge; Gil Violette, Doug Prosser, Claude Robichaud and Kevin Beattie for their industry expertise, our professors; Dr. Othman Nasir, Dr. Won-Taek Oh, Dr. Karl Butler, Dr. Kerry MacQuarrie and Dr. Bruce Broster for their technical knowledge and Chris Forbes and Dennis Conner for their help with our lab testing. Finally, Viraltec would like to thank our client Mike Pauley for his continued support.

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