September 12, 2019 Project No. 1662333

Srdjan Brasic, P.Eng.
Morrison Hershfield Limited
125 Commerce Valley Drive West, Suite 300
Markham, ON
L3T 7W4

SWELL LABORATORY TESTING RESULTS, PEEL CROSSINGS, QEW WIDENING FROM WEST OF MISSISSAUGA ROAD TO WEST OF HURONTARIO ROAD, CITY OF MISSISSAUGA
MTO, GWP 2002-13-00

Dear Sir:

Please find enclosed the results of the swell laboratory tests carried out on bedrock core samples obtained for the design of the watermain crossing Queen Elizabeth Way (QEW) at Station 15+825 and for the sanitary sewer crossing of the QEW at Station 16+560, associated with the widening of the QEW from west of Mississauga Road to west of Hurontario Road, City of Mississauga, Ontario. The swelling potential of the Georgian Bay Formation bedrock at the project site was investigated by conducting swell tests on bedrock core samples taken from Boreholes C1-2, C1-3, C3-1, C3-2, and C3-3 advanced as part of the foundation investigation for the above noted project and reported in the following Foundation Investigation and Design Reports (FIDR):

- Foundation Investigation and Design Report titled, "Watermain Installation at Station 15+825, QEW Widening from West of Mississauga Road to West of Hurontario Street, City of Mississauga, Ministry of Transportation, Ontario, GWP 2002-13-00" dated July 30, 2019 (MTO GEOCRES No. 30M12-447).
- Foundation Investigation and Design Report titled, "Sanitary Sewer Installation at Station 15+850, QEW from West of Mississauga Road to West of Hurontario Street, Mississauga, Ministry of Transportation, Ontario, GWP 2002-13-00" dated July 30, 2019 (MTO GEOCRES No. 30M12-448).
- Foundation Investigation and Design Report titled, "Sanitary Sewer Installation at Station 16+560, QEW Widening from West of Mississauga Road to West of Hurontario Street, Mississauga, Ontario, Ministry of Transportation, Ontario, GWP 2002-13-00" dated July 30, 2019 (MTO GEOCRES No. 30M12-449).

The tests were carried out at by K.Y. Lo Inc. at Western University in London, Ontario. During the swell tests the samples were subjected to either:

- Free swell conditions (samples were tested with no applied pressure allowing free swelling of the sample);
- Semi-confined swell conditions (samples were tested at a set applied horizontal or vertical pressure);
- Null swell conditions (full restriction of swelling in the direction of the sample axis and measuring of the pressure applied to the sample to suppress the swelling).

Null swelling, semi-confined swelling and free swelling tests were carried out on rock samples in the horizontal (sample axis along the bedding planes) and vertical (sample axis perpendicular to the bedding planes) directions. The testing also included the determination of the water content, salinity of the pore fluid in the test specimen, and calcite content of the bedrock core samples. The swell testing results for the free swell tests are presented as swelling strains (in %) versus time (in log scale to base 10) curves. The swell testing results for the null swell tests are presented as the pressures applied to the samples versus time (in natural scale) curves. The swell testing results for the semi-confined swelling conditions are presented as swelling strains (in %) versus time (in log scale to base 10) curves.

Golder's analysis of the results from horizontal and vertical free swell tests along with the calcite content are presented in Table 1. The results indicate that the suppression pressure for the shale bedrock from the Georgian Bay Formation in the vertical direction is higher than in the horizontal direction.

Table 1: Free Swelling Potential of Georgian Bay Shale (2 tests on samples with horizontal orientation, 2 tests on samples with vertical orientation)

	HSP[1] (X) [% per log cycle]	HSP[1] (Y) [% per log cycle]	Average HSP[1] (X+Y)/2 [% per log cycle]	VSP[2] (Z) [% per log cycle]	Calcite Content (%)
Range	0.17, 0.19	0.17, 0.18	0.18	0.57, 0.57	1, 3.2
Average	0.18	0.18	--	--	2.1

[1] HSP Horizontal Swelling Potential
[2] VSP Vertical Swelling Potential

The maximum pressure applied during null swell tests to suppress the swelling of the bedrock core sample along with the calcite content is shown in Table 2.

Table 2: Swelling Suppression Pressure for Georgian Bay Shale (1 test on sample with vertical orientation and 2 tests on samples with horizontal orientation)

	Horizontal Suppression Pressure [MPa]	Vertical Suppression Pressure [MPa]	Calcite Content [%]
Range	0.47, 0.78	2.5	1.2, 1.4, 3.2
Average	0.63	--	1.9

Golder's analysis of the results from horizontal and vertical semi-confined swell tests indicates the following semi-confined swelling potential of the shale bedrock, see Table 3 and Table 4.

Table 3: Semi-Confined Swelling Potential Horizontal Orientation (2 tests)

Applied Horizontal Pressure [MPa]	HSP[1] (X) [% per log cycle]	Calcite Content [%]
0.25	0.02	1.0
0.25	0.03	2.5

[1] HSP Horizontal Swelling Potential

Table 4: Semi-Confined Swelling Potential Vertical Orientation (2 tests)

Applied Vertical Pressure [MPa]	VSP[1] (Y) [% per log cycle]	Calcite Content [%]
0.3	0.06	2.1
0.35	0.04	1.0

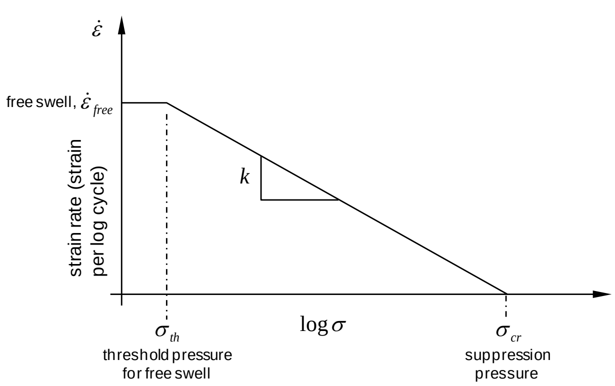
[1] VSP Vertical Swelling Potential

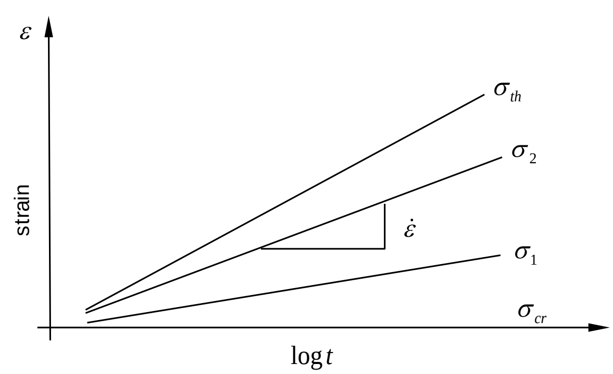
Time-Dependent Rock Deformation (Swelling)

Based on current knowledge, the time dependent swelling mechanism observed in the shale bedrock of the Georgian Bay Formation is a result of the dilution of pore water salt concentration that causes the space between the clay particles to expand[1]. The dilution is a result of osmosis and diffusion processes which allow water to move into the shale due to negative pore pressure if the rock is surrounded by a fluid of lower salt concentration. Therefore, preconditions for swelling to occur are accessibility to fresh water and an outward gradient of salt concentration from the pore fluid to the ambient fluid. The relief of in-situ stresses in the rock is considered the initiating mechanism for swelling to occur and the swelling potential is affected by the inter-particle bonding. If the bond strength is higher than the osmotic pressure, no swelling will occur and vice versa. The bond strength is governed by the calcite content of the bedrock which acts as a cementing agent between the clay particles. Other compounds such as iron oxide or aluminum oxide may also act as cementing agents.

The time-dependent deformation (swelling) characteristics of shale is generally expressed in terms of the swelling potential of the shale which is defined as the swelling strain measured per log (base 10) cycle of time in days (e.g., between 10 and 100 days), in both the vertical (perpendicular to bedding) and horizontal (parallel to bedding) directions under free swelling and semi-confined conditions.

The swelling potential is also noted to be stress dependent. The swelling potential (swelling strain rate) has been observed to be linear with the logarithm (base 10) of the confining pressure between the swelling suppression pressure and the free swell threshold pressure. These observations are the basis for the numerical model describing the swelling behaviour and are graphically and mathematically represented as follows:





[1] Lo, K.Y. and Micic, S. (2010), Evaluation of Swelling Properties of Shales for the Design of Underground Structures, ITA-AITES 2010 World Tunnel Congress, Vancouver, 2010

$$\dot{\varepsilon}_i = \begin{cases} 0 & , \quad \sigma_i > \sigma_{i\,\mathrm{cr}} \\ k_i \log\left(\dfrac{\sigma_i}{\sigma_{i\,\mathrm{cr}}}\right) & , \quad \sigma_{i\,\mathrm{cr}} > \sigma_i > \sigma_{i\,\mathrm{th}} \\ \dot{\varepsilon}_{i\,\mathrm{free}} & , \quad \sigma_{i\,\mathrm{th}} > \sigma_i \end{cases}$$

The following principles describe the swelling behavior of the rock:

i) The rock will swell freely at a prescribed rate when unconfined (free swell rate, $\dot{\varepsilon}_{\mathrm{free}}$);

ii) There is a confining pressure above which the rock will not swell (suppression pressure, σ_{cr});

iii) The swelling strain increases linearly with the logarithm of time; and

iv) The strain rate decreases linearly with the logarithm of confinement until it reaches zero at the suppression pressure.

Plots of the swelling potential of the Georgian Bay Shale versus the applied pressure (in log scale to base 10) under free swell, semi confined, and null swell conditions are presented in Figures 1 and 2 below for the horizontal and vertical directions, respectively. For plotting purposes, the free swell potential under free swelling conditions is assumed to be under a free swell threshold pressure of 0.001 MPa. The dashed lines on the plots indicate the upper and lower bound swelling envelopes for the horizontal and vertical directions, respectively and is based on the current laboratory testing, previous experience with shale bedrock of the Georgian Bay Formation on other projects, and published data.

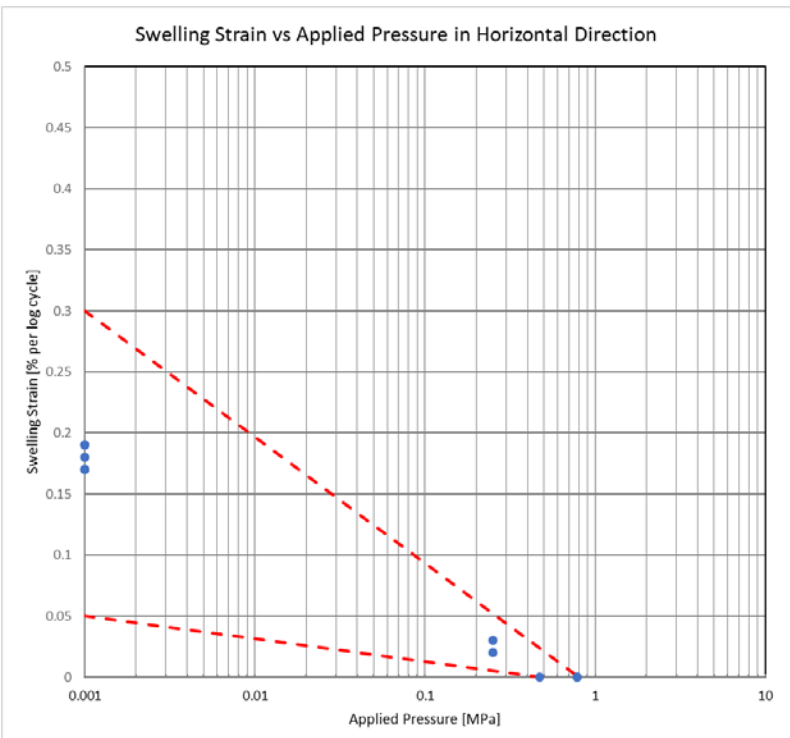


Figure 1: Swelling Potential vs Applied Pressure in Horizontal Direction (Georgian Bay Shale)

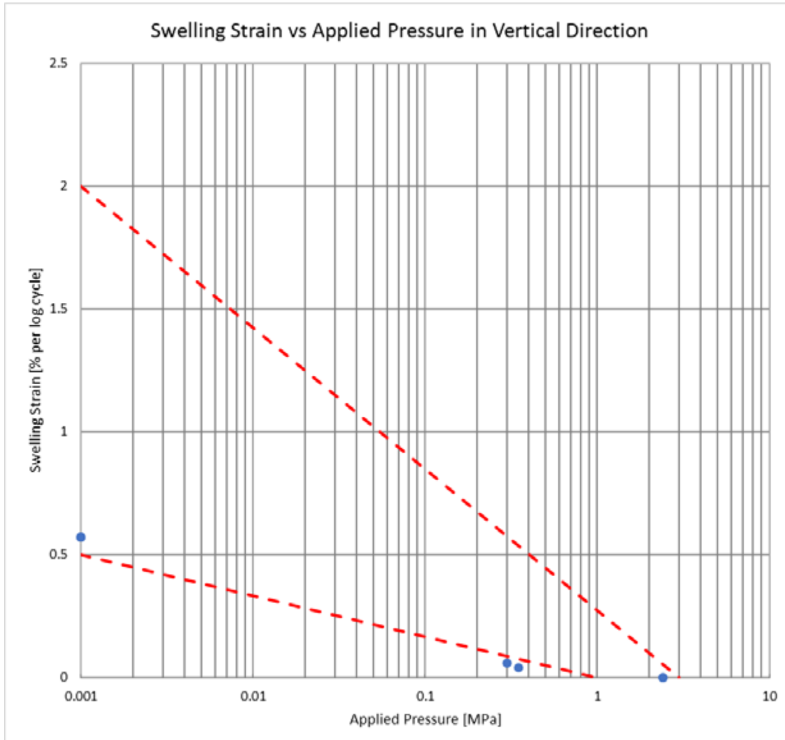


Figure 2: Swelling Potential vs Applied Pressure in Vertical Direction (Georgian Bay Shale)

The swelling characteristics of the Georgian Bay Shale, as assessed from the laboratory swell tests, will need to be taken into consideration for the design of the underground structures located within the shale. Regarding permanent structures such as the tunnel lining that will be in direct contact with the rock, the swelling of the rock will cause pressure to build up with time along the rock-structure interface. The magnitude of the pressure will depend on the rigidity of the structure, the time of construction after excavation of the rock, the swelling characteristics of the rock, and the initial in-situ stresses in the rock formation. Based on the swell testing carried out on samples from Boreholes C1-2, C1-3, C3-1, C3-2, and C3-3, the swelling rates as provided above should be considered in the tunnel and shaft design. It should be noted that the swelling potential could vary across the project due to natural variations of the rock such as the salinity of the rock pore fluid and calcite content, the in-situ stresses, and the groundwater conditions.

Revisions to Foundation Investigation and Design Reports (FIDR) and Subsurface Conditions Baseline Reports (SCBRs)

Prior to the completion of the laboratory swell test results, recommendations for baseline swelling potentials and baseline suppression pressures, based on previous experience with shale bedrock of the Georgian Bay Formation on other projects, and published data, were provided in the following Foundation Investigation and Design Reports and Subsurface Conditions Baseline Reports:

- Foundation Investigation and Design Report titled, "Watermain Installation at Station 15+825, QEW Widening from West of Mississauga Road to West of Hurontario Street, City of Mississauga, Ministry of Transportation, Ontario, GWP 2002-13-00" dated July 30, 2019 (MTO GEOCRES No. 30M12-447).

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- Subsurface Conditions Baseline Report titled, "Watermain Installation at Station 15+825, QEW Widening from West of Mississauga Road to West of Hurontario Street, City of Mississauga, Ministry of Transportation, Ontario, GWP 2002-13-00" dated July 31, 2019 (MTO GEOCRES No. 30M12-452).
- Subsurface Conditions Baseline Report titled, "Sanitary Sewer Installation at Station 15+850, QEW Widening from West of Mississauga Road to West of Hurontario Street, City of Mississauga, Ministry of Transportation, Ontario, GWP 2002-13-00" dated July 31, 2019 (MTO GEOCRES No. 30M12-456).
- Subsurface Conditions Baseline Report titled, "Sanitary Sewer Installation at Station 16+560, QEW Widening from West of Mississauga Road to West of Hurontario Street, City of Mississauga, Ministry of Transportation, Ontario, GWP 2002-13-00" dated July 31, 2019 (MTO GEOCRES No. 30M12-457).

Based on the results of the laboratory swell tests the recommendations and baselines as presented in the above reports are superseded with the revised baselines as follows: the swelling potentials for horizontal free swell rates will range from 0.05% to 0.3% per log cycle of time and vertical free swell rates will range from 0.5% to 2.0% per log cycle of time, with a baseline suppression pressure of between 0.5 and 0.8 MPa and between 1 MPa and 3 MPa in the horizontal and vertical direction, respectively. The lining should be checked for all loading cases including different combinations of the horizontal and vertical swelling, which may result in higher forces and moments.

CLOSURE

Golder Associates Ltd.

Sandra McGaghran, M.Eng., P.Eng.
Associate, Senior Geotechnical Engineer

Mark Telesnicki, P.Eng.
Principal, Rock Mechanics Engineer

J. Paul Dittrich, Ph.D., P.Eng.
Principal, MTO Foundations Designated Contact

KN/SMM/MJT/JPD/rb

Attachments: "Factual Results of Laboratory swell Tests on Rock Samples from QEW and Credit River Project, Mississauga, Ontario", dated August 13, 2019

https://golderassociates.sharepoint.com/sites/11176g/shared documents/07-reporting/foundations/12 - peel crossing fidr/swell testing letter/gwp 2002-13-00 ltr - swell_2019sept12.docx

K.Y. Lo Inc.

FACTUAL REPORT

Factual Results of Laboratory Swell Tests on Rock Samples from

QEW and Credit River Project

Mississauga, Ontario

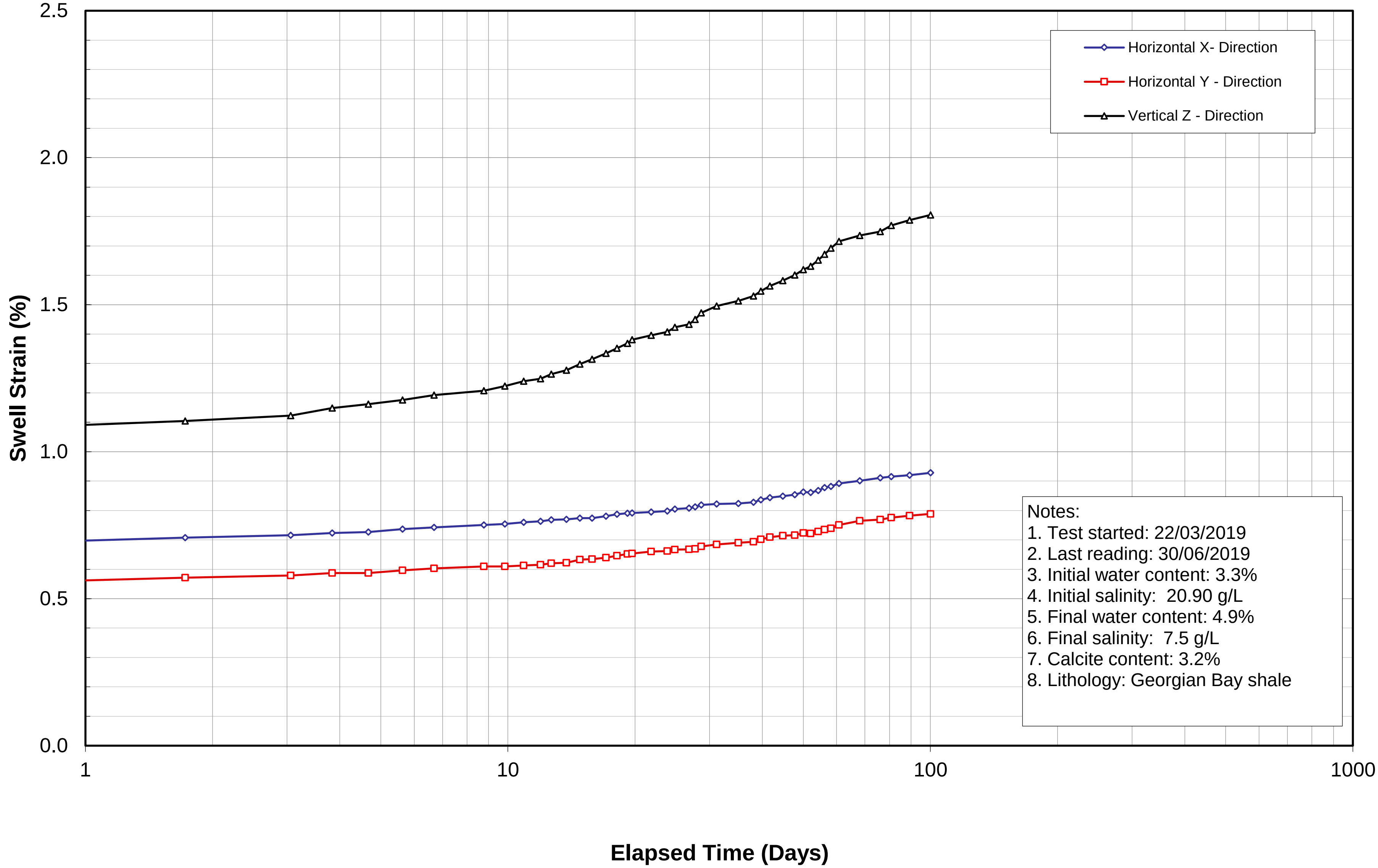
Prepared for:

Golder Associates Ltd.

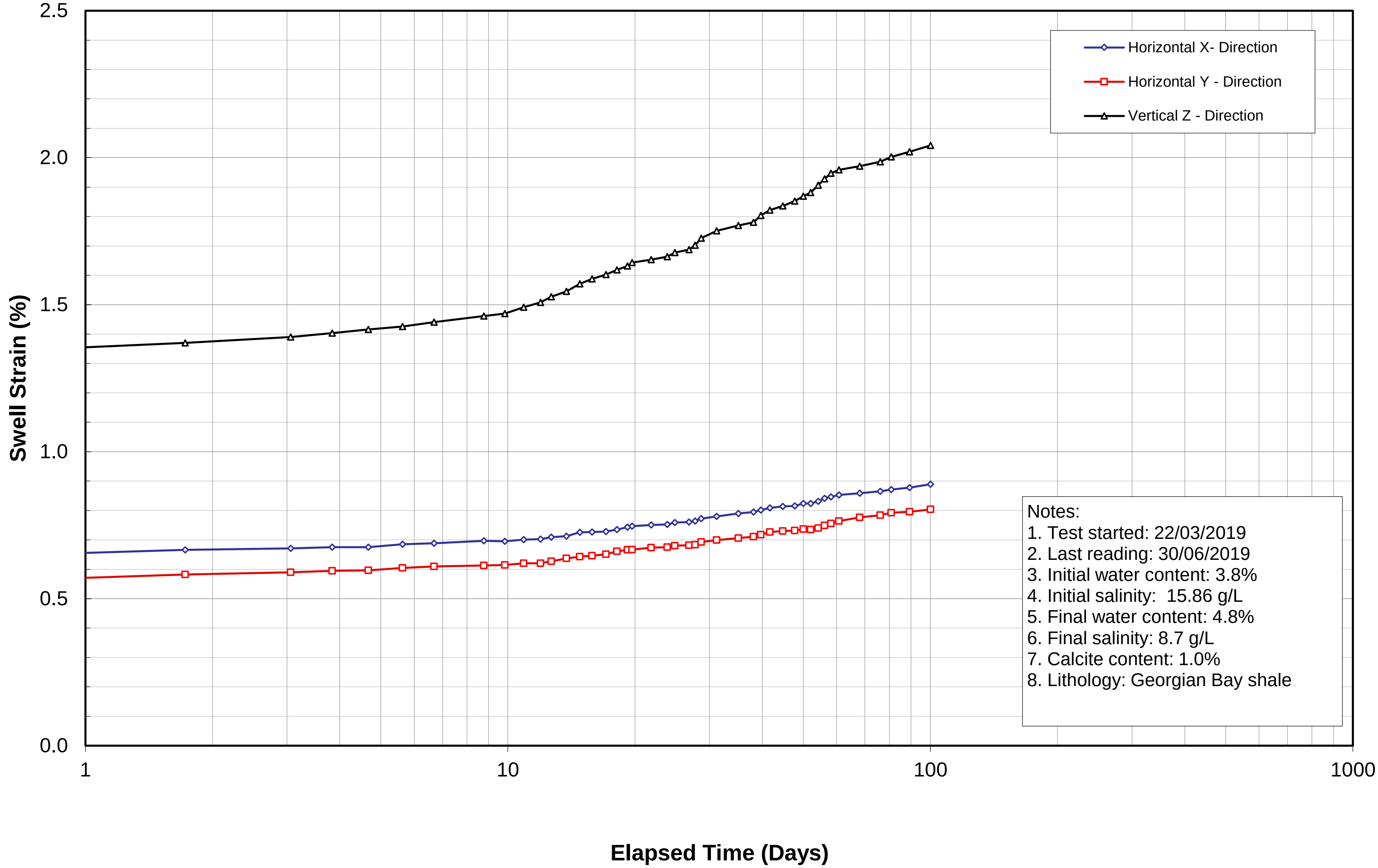
K. Y. Lo Inc.

August 13, 2019

Free Swell Test
QEW & Credit River
FST-C1-2-1
BH: C1-2, Depth: 5.46 m - 5.52 m

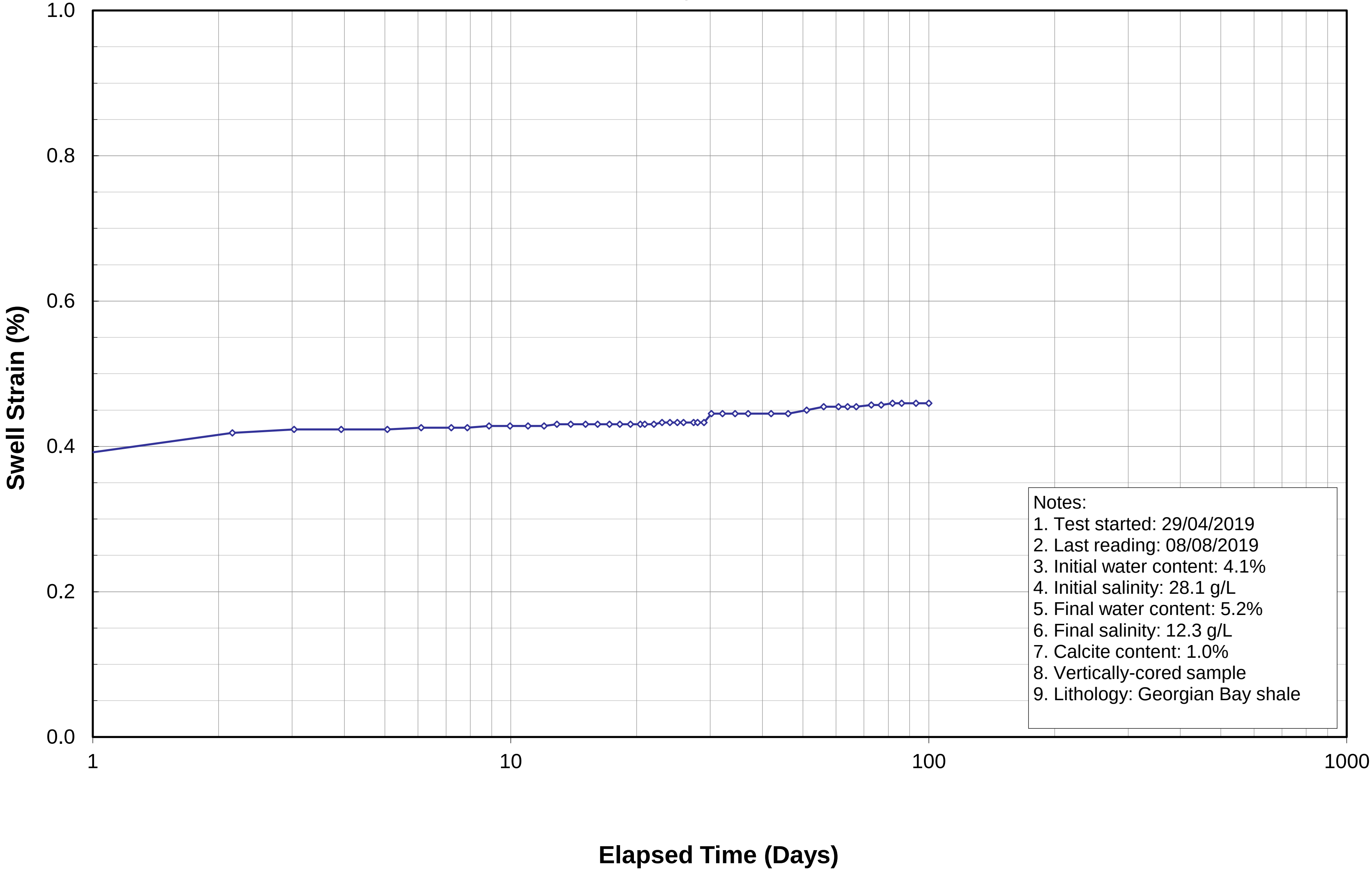


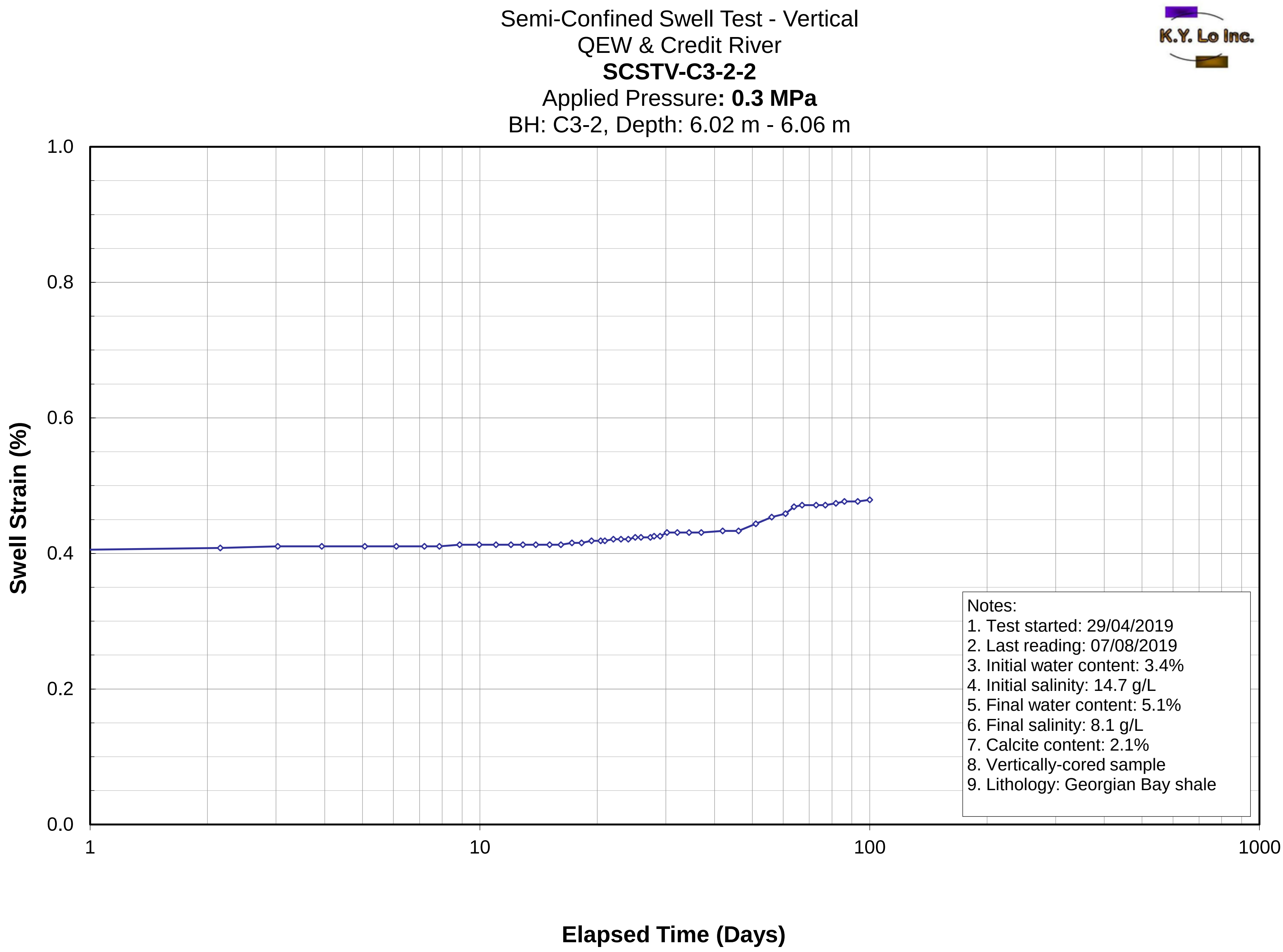
Free Swell Test
QEW & Credit River
FST-C3-3-2
BH: C3-3, Depth: 7.42 m - 7.48 m

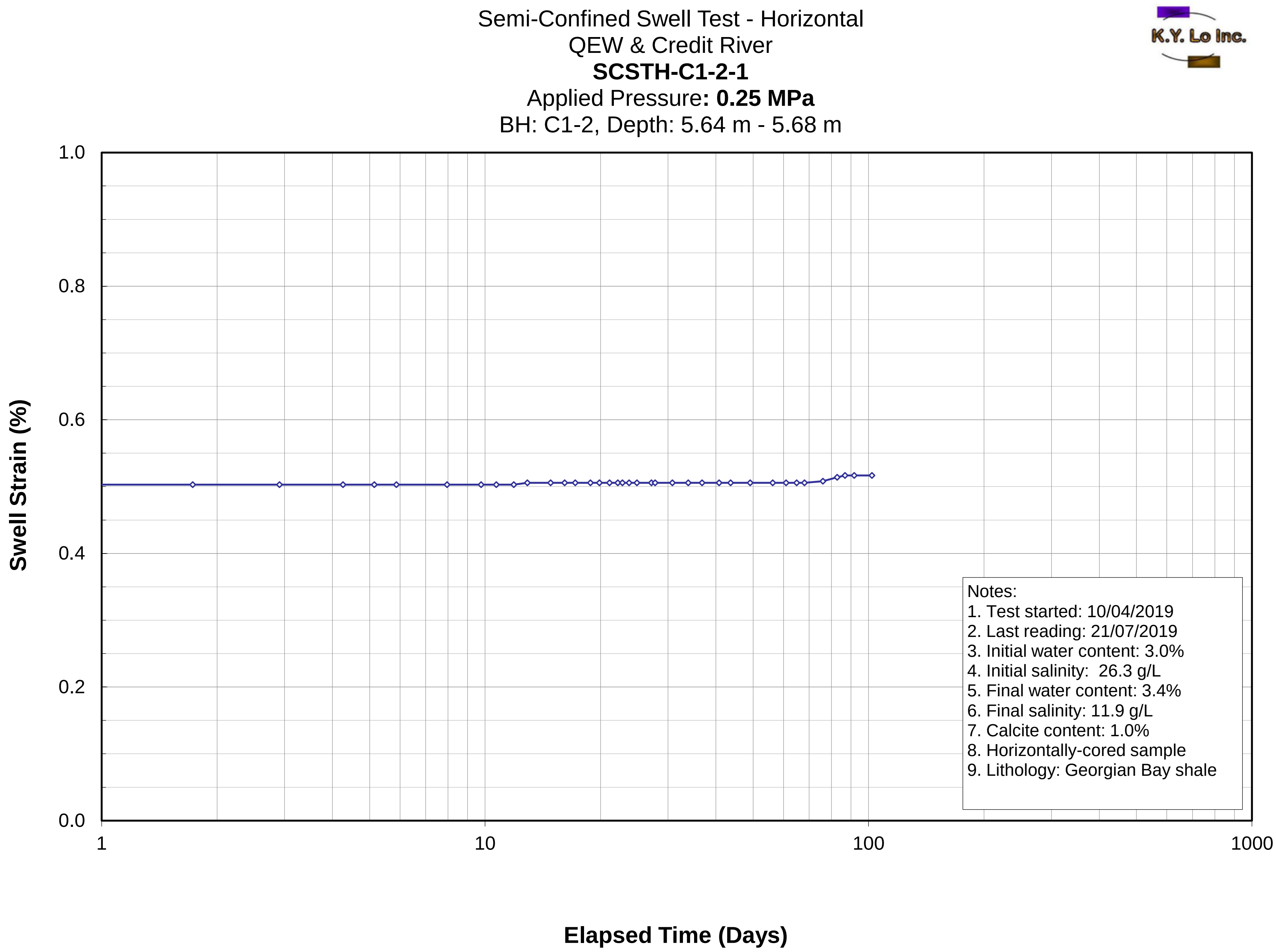


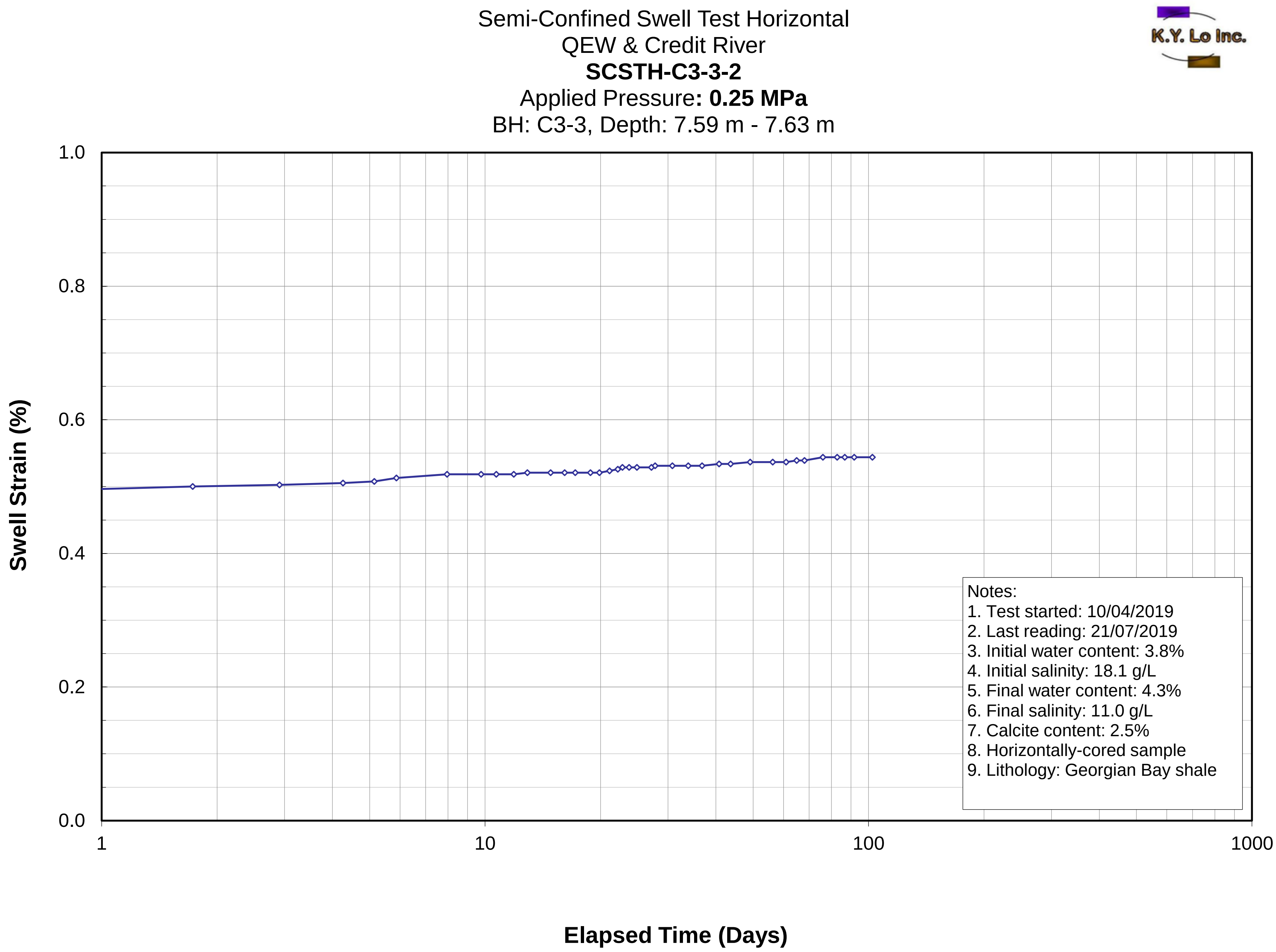
Notes:
1. Test started: 22/03/2019
2. Last reading: 30/06/2019
3. Initial water content: 3.8%
4. Initial salinity: 15.86 g/L
5. Final water content: 4.8%
6. Final salinity: 8.7 g/L
7. Calcite content: 1.0%
8. Lithology: Georgian Bay shale

Semi-Confined Swell Test - Vertical
QEW & Credit River
SCSTV-C1-3-1
Applied Pressure**: 0.35 MPa**
BH: C1-3, Depth: 7.65 m - 7.69 m

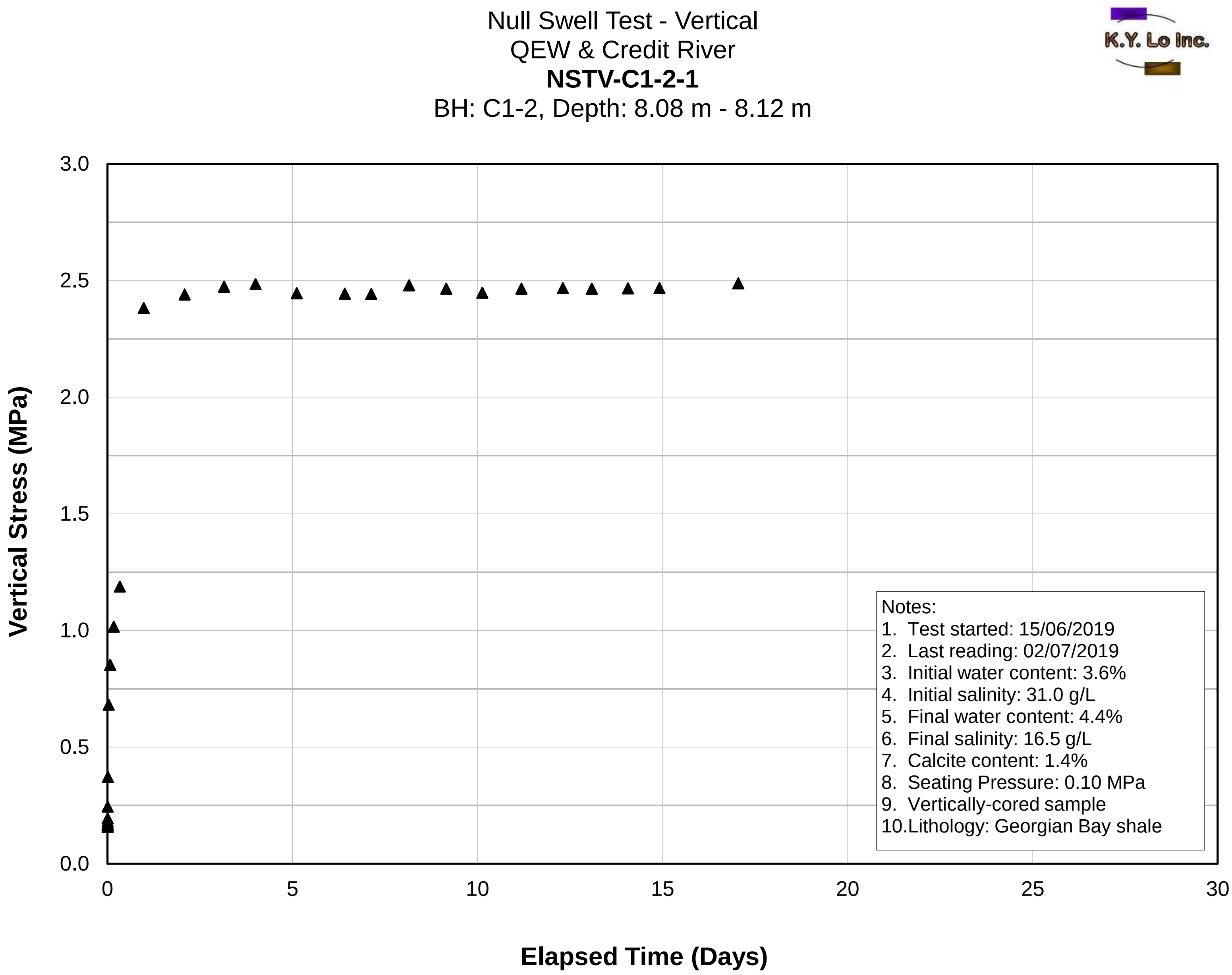



Semi-Confined Swell Test - Vertical
QEW & Credit River
SCSTV-C3-2-2
Applied Pressure: 0.3 MPa
BH: C3-2, Depth: 6.02 m - 6.06 m
K.Y. Lo Inc.
Swell Strain (%)
1.0
0.8
0.6
0.4
0.2
0.0
1
10
100
1000
Elapsed Time (Days)
Notes:
1. Test started: 29/04/2019
2. Last reading: 07/08/2019
3. Initial water content: 3.4%
4. Initial salinity: 14.7 g/L
5. Final water content: 5.1%
6. Final salinity: 8.1 g/L
7. Calcite content: 2.1%
8. Vertically-cored sample
9. Lithology: Georgian Bay shale

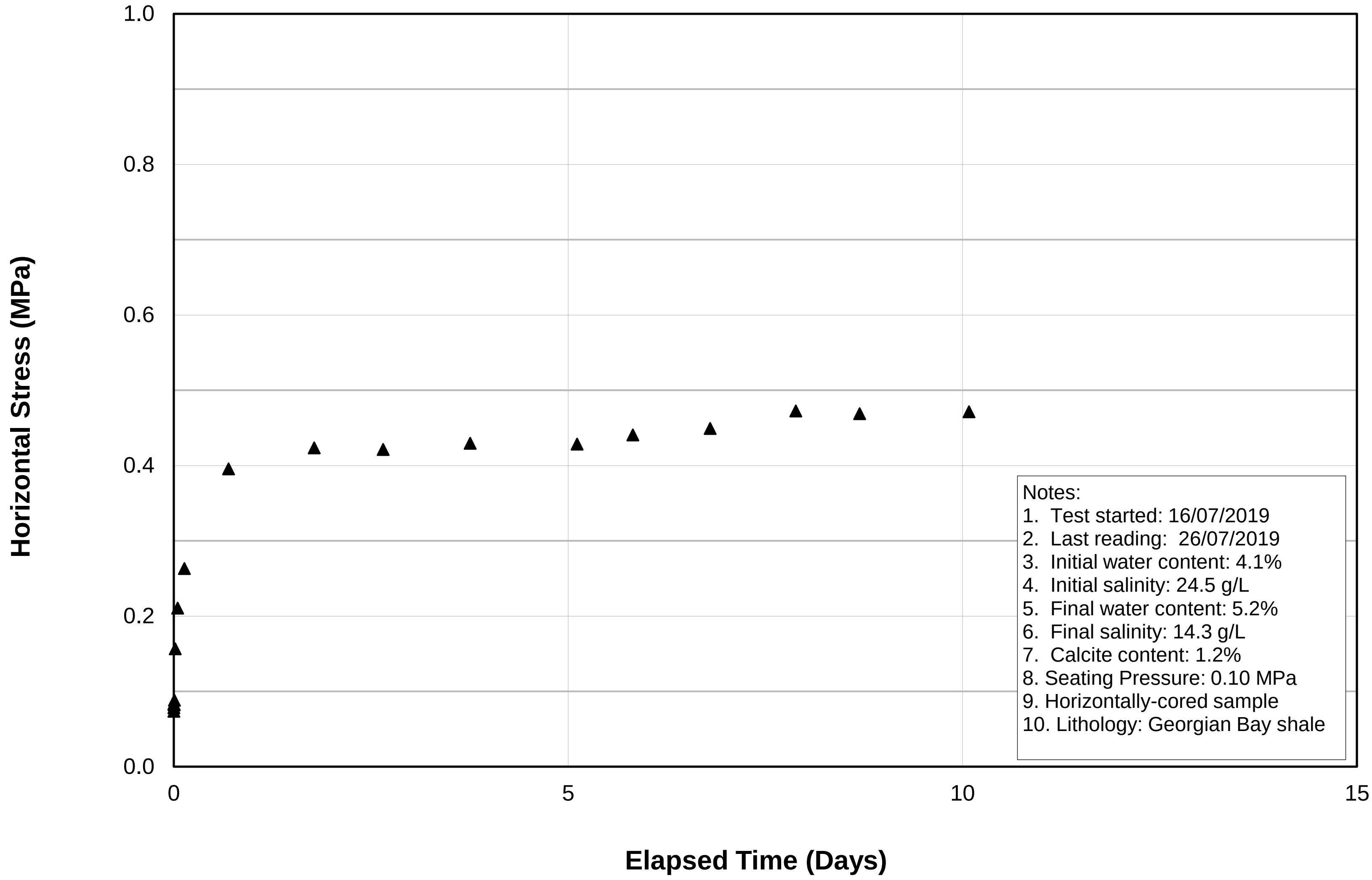

Semi-Confined Swell Test - Horizontal
QEW & Credit River
SCSTH-C1-2-1
Applied Pressure: 0.25 MPa
BH: C1-2, Depth: 5.64 m - 5.68 m
K.Y. Lo Inc.
Swell Strain (%)
1.0
0.8
0.6
0.4
0.2
0.0
1
10
100
1000
Elapsed Time (Days)
Notes:
1. Test started: 10/04/2019
2. Last reading: 21/07/2019
3. Initial water content: 3.0%
4. Initial salinity: 26.3 g/L
5. Final water content: 3.4%
6. Final salinity: 11.9 g/L
7. Calcite content: 1.0%
8. Horizontally-cored sample
9. Lithology: Georgian Bay shale

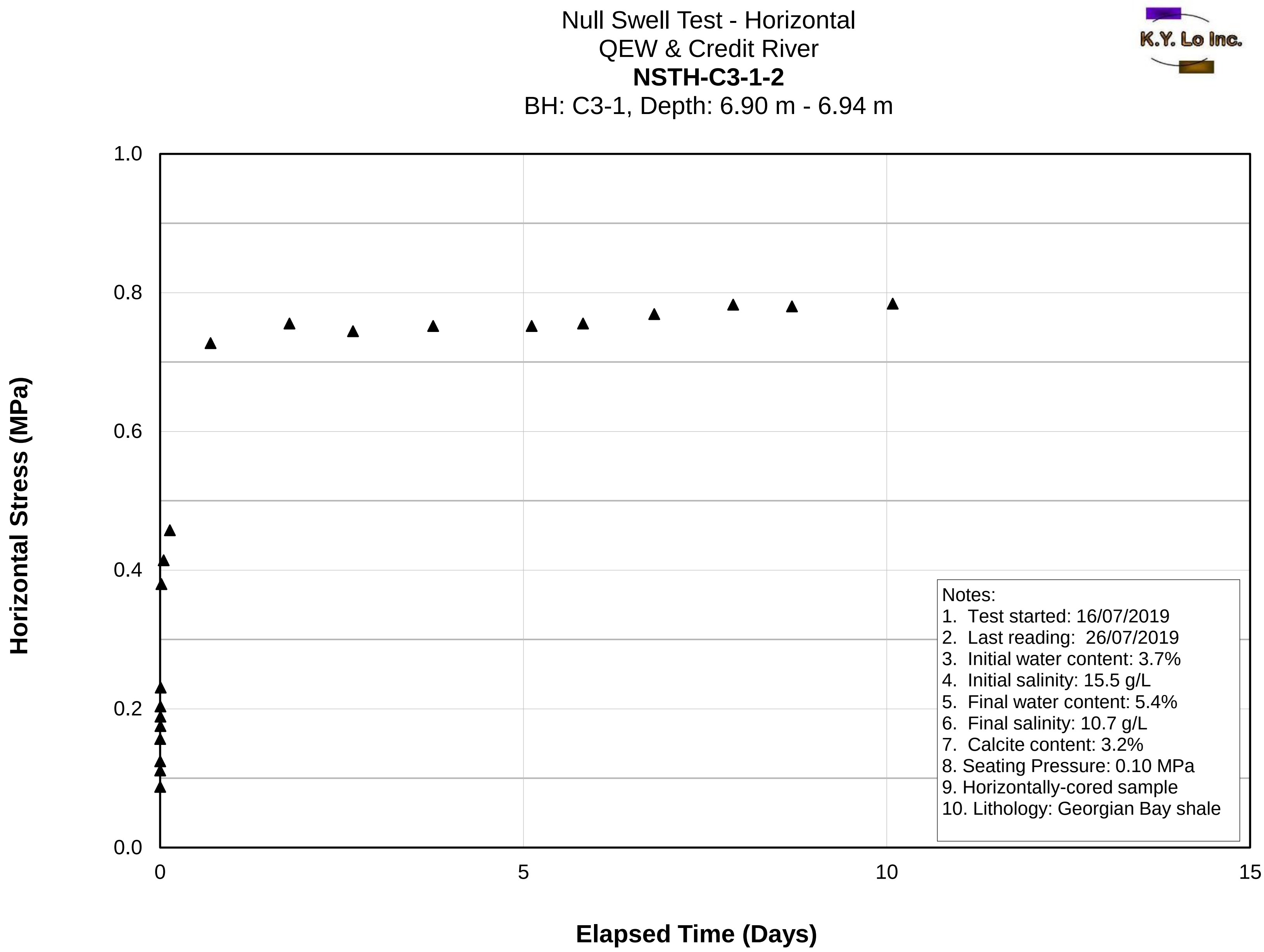


Semi-Confined Swell Test Horizontal
QEW & Credit River
SCSTH-C3-3-2
Applied Pressure: 0.25 MPa
BH: C3-3, Depth: 7.59 m - 7.63 m
K.Y. Lo Inc.
Swell Strain (%)
1.0
0.8
0.6
0.4
0.2
0.0
1
10
100
1000
Elapsed Time (Days)
Notes:
1. Test started: 10/04/2019
2. Last reading: 21/07/2019
3. Initial water content: 3.8%
4. Initial salinity: 18.1 g/L
5. Final water content: 4.3%
6. Final salinity: 11.0 g/L
7. Calcite content: 2.5%
8. Horizontally-cored sample
9. Lithology: Georgian Bay shale


Null Swell Test - Vertical
QEW & Credit River
NSTV-C1-2-1
BH: C1-2, Depth: 8.08 m - 8.12 m
K.Y. Lo Inc.
Vertical Stress (MPa)
Elapsed Time (Days)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
15
20
25
30
Notes:
1. Test started: 15/06/2019
2. Last reading: 02/07/2019
3. Initial water content: 3.6%
4. Initial salinity: 31.0 g/L
5. Final water content: 4.4%
6. Final salinity: 16.5 g/L
7. Calcite content: 1.4%
8. Seating Pressure: 0.10 MPa
9. Vertically-cored sample
10.Lithology: Georgian Bay shale

Null Swell Test - Horizontal
QEW & Credit River
NSTH-C1-2-1
BH: C1-2, Depth: 8.00 m - 8.04 m




Null Swell Test - Horizontal
QEW & Credit River
NSTH-C3-1-2
BH: C3-1, Depth: 6.90 m - 6.94 m
K.Y. Lo Inc.
Horizontal Stress (MPa)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
Elapsed Time (Days)
Notes:
1. Test started: 16/07/2019
2. Last reading: 26/07/2019
3. Initial water content: 3.7%
4. Initial salinity: 15.5 g/L
5. Final water content: 5.4%
6. Final salinity: 10.7 g/L
7. Calcite content: 3.2%
8. Seating Pressure: 0.10 MPa
9. Horizontally-cored sample
10. Lithology: Georgian Bay shale