ENGINEERING

LABORATORY

PRELIMINARY GEOTECHNICAL INVESTIGATION

851 INDUSTRIAL AVENUE, OTTAWA, ONTARIO

400 Esna Park Drive, Unit 15
Markham, ON
L3R 3K2

Tel: (905) 475-7755
Fax: (905) 475-7718

www.fisherenvironmental.com

Integrated solutions since 1989

Project No. FE-P 17-8323

September 6, 2017

Issued to: Dymon Group of Companies

Contact: Bliss Edwards
2-1830 Walkley Road
Ottawa, ON
K1H 8K3

Project Name: Preliminary Geotechnical Investigation

Project Address: Proposed Redevelopment, 851 Industrial Ave., Ottawa, Ontario

Project Number: FE-P 17-8323

Issued on: September 6, 2017

Project Manager:
(Primary Contact)

Sean Fisher, M.Sc. Eng.,
Project Manager
sean@fisherenvironmental.com

Report Prepared By:

Clive Wiggan. PhD. (Geotechnical), EIT.,
Geotechnical Technician
clive@fisherenvironmental.com

Report Reviewed By:

Frank Fan

LICENSED PROFESSIONAL ENGINEER
M. FAN
100154673
PROVINCE OF ONTARIO

Frank Fan, PEng.,
Geotechnical Engineer
Frank@fisherenvironmental.com

TABLE OF CONTENTS

1.0 INTRODUCTION

Fisher Environmental Limited (Fisher) was commissioned by the Dymon Group of Companies to conduct a Geotechnical Investigation for the proposed redevelopment of the property at 851 Industrial Ave., Ottawa, hereinafter referred to as the 'Site'.

The purpose of this investigation was to assess the subsurface soil and groundwater conditions at the Site and to outline geotechnical parameters and make recommendations for the design of the proposed redevelopment.

Concurrent to this geotechnical investigation, an environmental investigation program involving the drilling of 7 boreholes with Standard Penetration Test (SPT) and soil sampling was also implemented at the site. The subsoil conditions for this report were assessed based on all boreholes advanced at the site. In the absence of a detailed Site Plan, this report should be considered preliminary in nature and further investigations may be required during construction.

Discussion of the findings and results of the geotechnical investigation is in accordance with the general terms of reference. This report was prepared specifically and solely for the purpose of assessing geotechnical conditions as they relate to the development of the site with respect to the proposed structures as detailed to Fisher at the time of the investigation.

2.0 SITE AND PROJECT DESCRIPTIONS

The Site is located on the eastern side of Industrial Avenue, approximately 1200m south of the on ramp of St Laurent Boulevard and Highway 417. The Site is bounded by Industrial Avenue to the west and commercial and industrial properties to the north, east and south. The property is approximately 0.9 hectare (2.22 ac) in area. A commercial building, with five (05) vehicle bays and currently occupied by Budget Car and Truck Rental, is located along the northeastern section of the property. The remaining areas of the Site are covered with asphalt paving and landscaped grass, with trees along the perimeter.

The Site topography is fairly flat with a slight slope from the existing building easterly towards BH2 and BH3 with corresponding elevation changes, referencing the chosen benchmark, from 100m to 98.49m. It is expected that the Site will have ground surface graded to suit the proposed developments.

The proposed site development plan provided to Fisher prior to the Site investigation shows the construction of a building comprising 8,000sf retail, 18,900sf storage, 4,000sf reception area and an internal loading area of 8,800sf. The plan also shows the development of approximately 24 and 20 parking spaces to the south and west respectively of the proposed building.

Our investigation and recommendations presented herein should be considered preliminary.

3.0 FIELD AND LABORATARY WORK

Site drilling work for the geotechnical investigation was carried out on July 25 and 26, 2017 and consisted of seven (7) boreholes (BH1 to BH7). The boreholes were drilled at approximate locations as detailed on the attached Site Plan - Appendix A. Boreholes drilled at this time were advanced to depths from 6.5m (21.5’) to 10.9m (36’), unless refusal of the drill auger was encountered, with corresponding elevations ranging from 88.11m to 93.03m.

A Diedrich D-90 Truck mounted drilling rig equipped with hollow stems from Terra Firma Services was used for drilling work. Soil samples were taken at regular intervals using a split–spoon sampler advanced by means of the Standard Penetration Test (SPT) and was conducted in general accordance with ASTM specification D1586. Upon completion of drilling, the boreholes were backfilled with Bentonite.

All recovered soil samples were placed in clear, sealed plastic bags in the field and were transported to Fisher laboratory for further examination, characterization and laboratory analyses. Nine (9) representative soil samples from BH1, BH2 and BH3 were selected and submitted for moisture content analyses and six (06) samples from BH1, BH2 and BH3 were submitted for grain size distribution analyses. The results of the in-situ and laboratory tests are presented on the corresponding Log of Boreholes in Appendix B. The results of the grain size distribution analysis and moisture content tests are presented in Appendix C.

In addition three 50mm monitoring wells were installed in Boreholes BH1, BH5 and BH7 to monitor groundwater levels.

Fisher personnel surveyed the ground surface elevations using the finished floor elevation (FFE) of Bay #4 of the existing building as a temporary benchmark (TBM). The TBM was assigned an arbitrary elevation of 100m.

The soil samples recovered during the investigation will be stored in our laboratory for a period of 30 days after submitting this report and will be discarded thereafter unless otherwise instructed by the client.

4.0 SUBSOIL CONDITIONS

Examination of the soil conditions encountered in the boreholes show that the soil profile generally consists of asphaltic concrete underlain by sand and gravel fill on top of the native soils (silty sand / sandy silt and clay complex, including weathered shale) to the depth of termination. Subsoil encountered at borehole locations are shown on the Borehole Log Sheets, which are attached in Appendix B, and can be summarized as follows:

- **ASPHALTIC CONCRETE / GRAVEL** – A layer of asphaltic concrete was encountered in boreholes BH2 to BH7. The thickness of the layer ranged from approximately 50mm to 75mm. Coarse gravel was encountered in BH1 to a depth of 50mm.
- **FILL (Fine Sand / Silty Sand) –** Fill was encountered below the asphalt paving in Boreholes BH2 to BH7 and below the layer of gravel in BH1. The fill generally consisted of fine sand and silty sand, some gravel and asphalt with traces of wood, and extended in depth to about 4.2m below the existing grade. Traces of weathered shale, coal cinders and rootlets were found in the fill at BH5.

  The fine sand and silty sand were loose, brown in colour and wet in BH1 and BH4 while generally moist, compact and greyish brown in BH2, BH3 and BH5 to BH7. A layer of wet and very loose fill was observed in BH1 between 2.3m (7.5') and 3.5m (11.5') depth. BH1 was located in a former tank area and is generally not representative of the Site conditions.

  It should be noted that the thickness and the condition of the fine sand and silty sand fill could vary significantly between and beyond the borehole locations. Further investigations should be carried out during construction.

Table 1: Summary of Depth and Elevation of Fill

Borehole No.	**BH1**	**BH2**	**BH3**	**BH4**	**BH5**	**BH6**	**BH7**
Borehole Ground Elevation (m)	99.62	98.49	98.54	99.02	99.53	99.55	99.87
Depth of Borehole (m)	8.03	6.12	5.00	10.91	7.88	6.52	9.55
Elev. at Bottom of BH (m)	91.59	92.37	93.54	88.11	91.65	93.03	90.32
Depth of Fill / topsoil (m)	4.24	2.25	0.93	0.75	2.50	2.25	2.10
Elev. at Bottom of Fill (m)	95.38	96.24	97.61	98.27	97.03	97.3	97.77

- **SILTY SAND** – A layer of silty sand with gravel was encountered in Boreholes BH1 to BH7 below the fine sand and silty sand fill and extended to depths ranging from about 2.1m to 10m below the existing grade. The greyish brown to dark brown silty sand were moist to wet and in a loose to compact condition, but generally of compact relative density. Clayey silt was also encountered below the silty sand in BH3, BH4 and BH6. The clayey silt was greyish brown, moist (wet at approximately 4m) and in loose to compact condition.

- **CLAY COMPLEX (CLAY, WEATHERED SHALE)** – Clay and weathered shale were encountered below the layer of silty sand in Boreholes BH1 to BH7. Six boreholes were terminated in the clay complex at depths ranging from 5m to 9.6m below the existing grade with corresponding elevation changes from 93.03m to 90.32m. Borehole BH4 terminated at auger refusal in weathered shale at approximately 11m depth (elevation of 88.11m). The dark grey clay complex with shale and occasional trace of gravel, were in moist to dry condition and hard.

  Five SPT ‘N’ values (one per borehole) measured at the end of the boreholes (clay complex) varied from 62 to 100 blows per 0.3m, indicating a very dense relative density at depths greater than 6m while two (BH3 and BH6) indicated dense relative density with ‘N’ values of 34 and 48 at 6.5m and 5m respectively.

5.0 GROUNDWATER

Groundwater levels were measured in Boreholes BH1 to BH5 and BH7 during and on completion of drilling works. Borehole BH6 was mostly dry. Monitoring wells were installed in Boreholes BH1, BH5 and BH7 as shown in the Site Plan at Appendix A.

The results of the measurements are shown on the individual Records of Boreholes in Appendix B and summarized in Table 2.

Table 2: Groundwater Levels

Borehole No.	Date of Measurement	Depth of Groundwater below existing grade (m)	Groundwater Elevation (m)
BH1 (MW)	July 26, 2017	1.60	98.02
BH2	July 25, 2017	2.12	96.36
BH3	July 25, 2017	1.82	96.71
BH4	July 26, 2017	3.12	95.90
BH5 (MW)	July 26, 2017	3.2	96.33
BH6	July 26, 2017	dry	N/A
BH7 (MW)	July 26, 2017	3.9	95.97

It should be noted, however, that the groundwater levels at the Site are subject to seasonal fluctuations and to major weather events. Consequently, definitive information on the long-term groundwater levels could not be obtained at the time of the investigation.

6.0 FOUNDATION CONSIDERATIONS

It is understood that the proposed development will comprise storage, retail, reception and loading facilities units with 5- storey and no basement/ underground parking. As the exact Site Plan and Finished Floor Elevation (FFE) is unverified at this time, the findings and recommendations presented in this report should be considered preliminary

The Site's current use is industrial and is covered by a site building, asphalt paving and landscaped grass areas with trees on the perimeter. A layer of fill was encountered in all boreholes ranging from 1.2m to 4.5m bsg. Loose to compact silty sand / sandy silt deposits were encountered below the fill and generally underlain by a hard stratum of clay / silty sand / weathered shale complex and extended to the bottom of all boreholes.

SPT “N” values tested on the native strata, ranged from 1 to 32 blows per 300mm. SPT ‘N’ values for BH1 are particularly low indicating very loose to loose soil/fill to a depth of about 4.5m with corresponding ‘N’ values of 1 to 6. The native silty sands at depths of 4.5m to 7.6m were relatively compact with ‘N’ values of 11. It should be noted that BH1 was drilled in a former tank area and that the soils encountered above the silty sand layer are not representative of the general condition of the Site. SPT ‘N’ values for BH2 to BH4 at depths of 2 - 3m (±), 3 - 3.5m (±) and 4.5 - 5m (±) vary from 5 to 9 indicating a layer of loose soil. SPT ‘N’ values for BH5 to BH7, at depths greater than 2.3m, were generally higher than 11 blows per 300 mm, indicating a compact relative density.

The investigation showed that the native soils (silty sand and sandy silt with gravel and trace clay) encountered on the Site are of a loose to compact relative density. The depth at which native soils, suitable for supporting conventional foundations, were encountered however varies. Therefore, conventional strip / spread / mat footings should be extended to the competent stratum, where feasible. Geotechnical resistances of 150 - 200 kPa (SLS) and 210 - 280 kPa (factored ULS) may be used for the design of footings placed at various depths below the existing grade as shown in Table 3. Alternatively, deep foundations in the form of caissons, piles or a combination of deep foundations and conventional (strip / spread and or mat) foundations may be considered. The resulting space below the existing grade could also be developed as basement and or parking. Final design would be dependent on building loads, local conditions and the experience of the contractors.

Based on the groundwater levels encountered during boring, excavation for shallow foundations is likely to extend below the groundwater table. The groundwater table must therefore be lowered to at least 1.0m below the deepest excavation base. Appropriate groundwater exclusion and or extraction methods should be considered for construction.

Given the proposed building structure, the following foundations/footings may be considered.

6.1 Spread/ Strip Footing Found on Native Soils

Recommended approximate founding depths / elevations and corresponding bearing resistance for limit states (SLS and ULS) are presented in the Table 3.

Table 3: Foundation Design for Conventional Footings

Building/Borehole			Elev. of BH Ground (m)	Approx. Depth of Footings at or below (m)	Approx. Elevation of Footings at or below (m)	Bearing Resistance at SLS (KPa)	Bearing Resistance at ULS (KPa)
Proposed Industrial / Commercial Structures	**[1]BH1**	**No Basement/ Underground Garage**	99.62	4.54	95.08	[4]150	[4]210
	[2]BH2		98.49	3.00	95.49	[4]150	[4]210
	[2]BH3		98.54	3.79	94.75	[4]200	[4]280
	[3]BH4		99.02	2.27	96.75	200	280
	BH5		99.53	2.27	97.26	150	210
	BH6		99.55	1.65	97.90	200	280
	BH7		99.87	1.97	97.90	150	210

Note:

1. Incompetent layers were detected from 2.2 to 4.5m in BH1 (former tank area).

2. Incompetent layers were detected from 2.2 to 2.7m and from 3 to 3.5m in BH2 and BH3 respectively.

3. Incompetent layer was detected at a depth of 4.5m in BH4. Footing should not be founded between 2.5m and 4.5m below existing grade.

4. Loose soil encountered in layer(s) above. This depth could present construction challenges for supporting shallow foundations.

6.2 Raft Foundation

Considering the proposed building have no underground parking, and explored native subsoils were variable and incompetent as a bearing stratum for supporting foundation, the structure may be supported on a raft foundation founded in native undisturbed silty sand / sandy silt underneath fill and may with partially engineered fill layer. The designed raft slab must have a minimum soil cover of 1.5m for frost protection requirements in all exterior / unheated area.

The raft foundation may be proportioned using the following bearing resistance:

Bearing Resistance at SLS = 150KPa

Factored Bearing Resistance at ULS = 225KPa

For the preliminary design, as proposed raft foundation, subgrade reaction modulus (K) value of 9500KN/m^3 may be considered.

Based on the site subsoil conditions, the fill material was detected in all boreholes and extended to depths ranging from 1.2m (BH4) to 4.5m (BH1). For raft foundation construction, all fill material must be removed and replaced with engineered fill to design finished subgrade. It is recommended that Granular Class 'B' aggregates be used for engineered fill, especially during the winter time or wet season to raise grade up in the areas where fill material is removed.

The engineer fill pad using Granular Class 'B' aggregates should be covered with a minimum of 500mm thickness under raft slab wherever engineered fill is placed and also where the dimensions extend greater than 1.5m beyond the footprint of building or the equivalence of the depth to be filled up.

Prior to placing engineered fill the exposed native soil base must be thoroughly proof-rolled, after removal of organic soil / topsoil/ fill / construction debris /underside utilities, and the prepared base approved by engineering staff from our office. Any soft spots observed during proof rolling must be sub- excavated and back filled with suitable granular materials compacted to 98% SPMDD.

The engineered fill should be compacted in lifts of no more than 200mm in thickness and to at least 98 percent of the Standard Proctor Maximum Dry Density (SPMDD). A technician from Fisher must be involved in the engineered fill operations, carrying out onsite supervising, proof rolling, inspection and compaction testing.

It should be noted that for a raft foundation design settlement failure generally controls the soil bearing capacity. Due to the subject Site variable soil conditions and the presence of wet / less competent soils at /below the proposed underside of raft grades, we request that any preliminary raft foundation design be reviewed by this office followed by a settlement analysis.

Should the calculated settlement exceed the tolerable limits, deep foundation alternative such as drilled caissons should be considered.

6.3 Driven HP Pile or Drilled Caisson/Grade Beam Foundation System

For the proposed development, deep foundation alternatives including driven HP piles or drilled caissons are recommended.

Given encountered onsite subsoils, a driven HP pile / grade beam foundation system may be used. The piles would be founded into hard clay or sandy silt with weathered shale complex refusal at approximately depths of 6.6m to 8.2m below current grade.

For preliminary design / cost comparison purposes, using Meyerhof's method based on onsite SPT tests (using SPT 'N' = 50 blows/300mm for the refusal), a working load of 800 KN (pile toe resistance only considered at the current stage, and with a safety factor of 2) may be applied to an HP 360×109 steel pile founded into refusal at approximately 8.5m below current grade.

Actual pile factored loads should be determined /confirmed through a pile load field test.

Consultation with specialized pile foundation contractors is recommended to establish if noise and vibrations associated with piling operation will be acceptable within the properties urban surrounding.

Another deep foundation alternative would be drilled caisson/ Grade Beam Foundation System. The size of the caisson can be proportioned using the following bearing resistance:

Bearing Resistance at SLS = 1800 KPa

Factored Bearing Resistance at ULS = 2350 KPa

if founded into refusal at approximately 8.5m below current grade.

It should be noted that, for the design of the above deep foundations, further deep borehole investigation may be required in the south portion of the proposed building area covered by the current Boreholes BH3 and BH6. In addition, based on the indication of Ottawa Bedrock Map, the bedrock is expected to be reached at an approximate depth of 5m to 10m. This would be consistent with auger refusal encountered at the end of Borehole BH4. To conform / reveal bedrock depth and its conditions, three (3) deep boreholes are recommended to drill/coring into bedrock with a minimum coring depth of 3m into bedrock. With further confirmation of the bedrock depth and its conditions, the drilled caisson may be situated into the rock where higher bearing capacity is provided.

It should be reiterated that moist to wet silty sand deposit and / or boulders may be encountered during the drilled caisson installations. Contractor must be prepared to deal with boulders and/or water seepage into the caisson shafts without undue delays.

6.4 General Comments about Footing Construction

I. Adjacent footings founded at different elevations should be stepped at 10 horizontals to 7 verticals.

II. For frost protection requirements, all exterior footings and footings in unheated basement must have a minimum soil cover of 1.5m.

III. Footings designed to the above specified bearing pressure values are expected to settle less than 25 mm total and 19mm differential.

IV. The recommended bearing resistance and foundation elevations have been calculated from the limited borehole information and are intended for design purposes only.

V. More specific information with respect to soil conditions between and beyond the boreholes will be available when the proposed construction is underway. Therefore, the encountered soil/foundation conditions must be verified in field, and all footings must be inspected and approved by our office prior to placement of concrete.

7.0 EARTHQUAKE CONDITIONS

Geophysics GPR International Inc. conducted seismic shear wave surveys to determine the Site Classification for Seismic Site Response using Multi-channel Analysis of Surface Waves (MASW) and the Extended Spatial AutoCorrelation (ESPAC) complemented by the seismic refraction method.

Based on the seismic refraction testing, the depth to rock was estimated at between 5 and 6m with an average depth of 5.4m (±) 1m. The shallow rock shear wave velocity value was calculated as 1575 to 1625 m/s to a depth of 30m and the results used to build the geophysical models. The calculated $\frac{-}{V_{S30}}$value for the actual site is 896.3 m/s which correspond to the Site Class ‘B’ as shown in Appendix E.

Notwithstanding the above, the Ontario Building Code stipulates that, the Site Classes A and B are not to be used if there is more than 3m of unconsolidated materials between the rock surface and the bottom of the spread footing or the mat foundation. It is therefore recommended that once the type of footing is decided on that onsite test pits be excavated to determine the thickness of the soil between the base of the footing and the top of rock in order to conclude the exact Site Class to be used for design purposes.

In the absence of further bedrock depth information, and or for instances where depths to rock exceeds 3m, a Site Classification of C would be recommended.

8.0 BASEMENT WALLS

In the case that the proposed building was constructed with basement / underground garage then the basement wall should be designed to resist a pressure “p” at any depth “h” below the surface, as given by the expression:

$$\boldsymbol{p = 0.4[\Upsilon h + q]}$$

Where: 0.40 is the earth pressure coefficient considered applicable

Υ= 21.0 KN/m^3 is the unit weight of backfill

q = an allowance for surcharge in kpa.

The above equation assumes that a perimeter drainage system will be provided and that the backfill against subsurface walls, where applicable, would be a free draining granular material.

9.0 GROUNDWATER CONDITIONS

Groundwater levels were measured in six (6) boreholes, drilled on July 25 and 26, 2017, as shown in the attached Site Plan. The depth of ground water below existing grade ranged from 1.6m to 3.9m. Borehole BH6 was dry.

The recommended footing depths for the proposed development are that shallow footings be founded at or below 1.65m to 2.27m where competent strata exist for no basements/ underground parking constructions, and or deep foundations where competent soils are below 3m. In both scenarios, the measured onsite groundwater levels are generally higher than the recommended footing founding grades. Therefore, dewatering would be required under current site conditions.

It should also be noted that groundwater levels are subject to seasonal fluctuations. Consequently, definitive information on the long-term groundwater levels could not be obtained at the time of the investigation.

10.0 EXCAVATION AND BACKFILL

No major problems should be encountered for the anticipated depths of excavation for the footings / underground utilities. The excavations for footings or underground services must be carried out in accordance with the latest edition of the Occupational Health and Safety Act (OHSA). Specifically, if the excavation is deeper than 1.2m, the excavation sides should be sloped in accordance with the requirements of OHSA. If this condition cannot be met, a temporary shoring system/ trench box should be utilized.

In accordance with O. Reg. 213/91, S.226 (1), the Site subsoils within anticipated excavation depths mainly consist of loose to compact silty sand and sandy silt with some weathered shale / clay complex at greater depth. After removal of the topsoil / fill, the site soils can be designated as Type 3. This means that, for open excavation on the site, a 1:1 slope can be constructed.

The material to be used for backfill in service trenches should be suitable for compaction, i.e. free of organics and with moisture content within 2 percent of the optimum moisture value. The backfill material should be compacted in lifts of no more than 200mm in thickness and to at least 98 percent of the Standard Proctor Maximum Dry Density (SPMDD) in the upper 1.0m from road subgrade or in settlement sensitive areas. Beyond these zones, a 95% SPMDD compaction criterion is considered acceptable.

Additionally, on site excavated native soils can be used as backfill in service trenches, provided that the excavated materials are free of organic soils (topsoil / construction) debris and are of suitable moisture content.

It is recommended that Granular Class ‘B’ aggregates be used for backfill against the subsurface walls and footings. Granular materials excavated on-site may be acceptable subject to further site inspection.

11.0 SLAB ON GRADE AND PERMANENT DRAINAGE

For construction of the proposed building with no basement / underground parking, the finished floor slab can be constructed as slab on grade supported by competent native undisturbed sandy silt/ fine sand/silt /coarse sand deposits or an engineered fill pad (subject to design grade).

If engineered fill is required to raise subgrade for slab construction, the engineered fill must be placed on a thoroughly proof-rolled exposed base. Organic soil / topsoil/ fill / construction debris /underside utilities must be removed and the base approved, by engineering staff from our office, prior to placing the engineered fill. Any soft spots observed during proof rolling must be sub-excavated and back filled with suitable granular materials compacted to 98% SPMDD.

Onsite excavated native soils and selected fill materials can be used as engineered fill provide they contain suitable moisture content. The use of granular Class 'B' aggregates is however preferred for subgrade construction for slab on grade, especially during the winter time or wet season.

Similarly, it is recommended that granular Class 'B' aggregates be used for backfill against subsurface walls. Subject to further site inspection, suitable onsite granular materials may however be used.

Upon completion of foundation work, the floor slab should rest on a well compacted bed of size 19 mm clear stone of at least 200 mm thick. The stone bed would act as a barrier and prevent capillary rise of moisture from the subgrade to the floor slab.

A permanent perimeter drainage system for open excavation / foundation walls should be provided as shown in the drainage design recommendation at Appendix D.

12.0 UNDERGROUND UTILITIES

Pipe bedding and backfill materials specifications and compaction criteria for water and sewer services should be in accordance with the pipe designer's recommendations and/or local municipal requirements.

If the excavation is deeper than 1.2m, the excavation sides should be sloped in accordance with requirements of OHSA. If this condition cannot be met, a temporary shoring system or trench box should be introduced.

For the subject site, it is expected that the underground services will be founded above the water table and situated in compact silty sand / sandy silt. Granular Class 'B' aggregate is considered well suited to be used as bedding material. However, it should be noted, that the recommended type of bedding is to be placed on undisturbed subgrade. If the construction methods will disturb the subgrade i.e. piping, existing footing, boulder removal etc. or existence of excess hydrostatic pressure, then higher-class bedding combined with a geotextile may have to be used.

Onsite excavated fill materials / native soils are considered suitable for re-use in trench backfilling, provided that organics (topsoil) / construction debris are removed and that materials are not allowed to be wet and the moisture content is within 2% of the optimum moisture content.

In normal sewer construction practice, the problem of road / pavement settlement largely occurs adjacent to manholes, catch basins and service crossings. In these areas, granular materials are generally required for backfill and compaction.

Water lines installed outside of heated areas should be provided with a minimum of 1.2 m soil cover or equivalent for frost protection.

13.0 PAVEMENT

It is expected that the associated pavement for driveways and parking areas will be developed on the site. Pavement structures can be constructed on the native soils or engineered fill, subject to design grade and further onsite inspection.

Prior to asphalt pavement construction, topsoil/organic soil/ construction debris should be removed. The exposed base should be proof rolled and supervised / approved by our office. Any soft / spongy spots detected during proof-rolling should be sub-excavated and replaced with suitable materials and compact to 98% of SPMDD. Engineered fill construction, if any, should be supervised and inspected by engineering staff from our office.

The finished subgrade must be contoured / graded and finally proof-rolled and approved by our office before placing upper granular materials.

Granular materials will be used in construction of asphalt pavement bases. Compaction for granular bases should reach 100 % of Standard Proctor Maximum Dry Density,

Perforated drains connected to sewer MHs/ CBs should be provided under the entire length of curb and constructed in accordance with required local regulations.

Typical flexible pavement designs are shown in Table 4.

Table 4: Typical flexible pavement design

	Heavy Duty	**Medium Duty**	**Light Duty**
Asphaltic Concrete	40 mm HL3	40 mm HL3	50 mm HL3
	65 mm HL8	50 mm HL8	
19 mm Crushed Limestone	150 mm	150 mm	200 mm
Granular B Sub-base	300 mm	200 mm	

The pavement thickness should also meet the minimum local region Pavement Design Standards.

The asphalt material should meet the requirements of OPSS 310 for specified grade and be compacted to at least 92% of their maximum relative density.

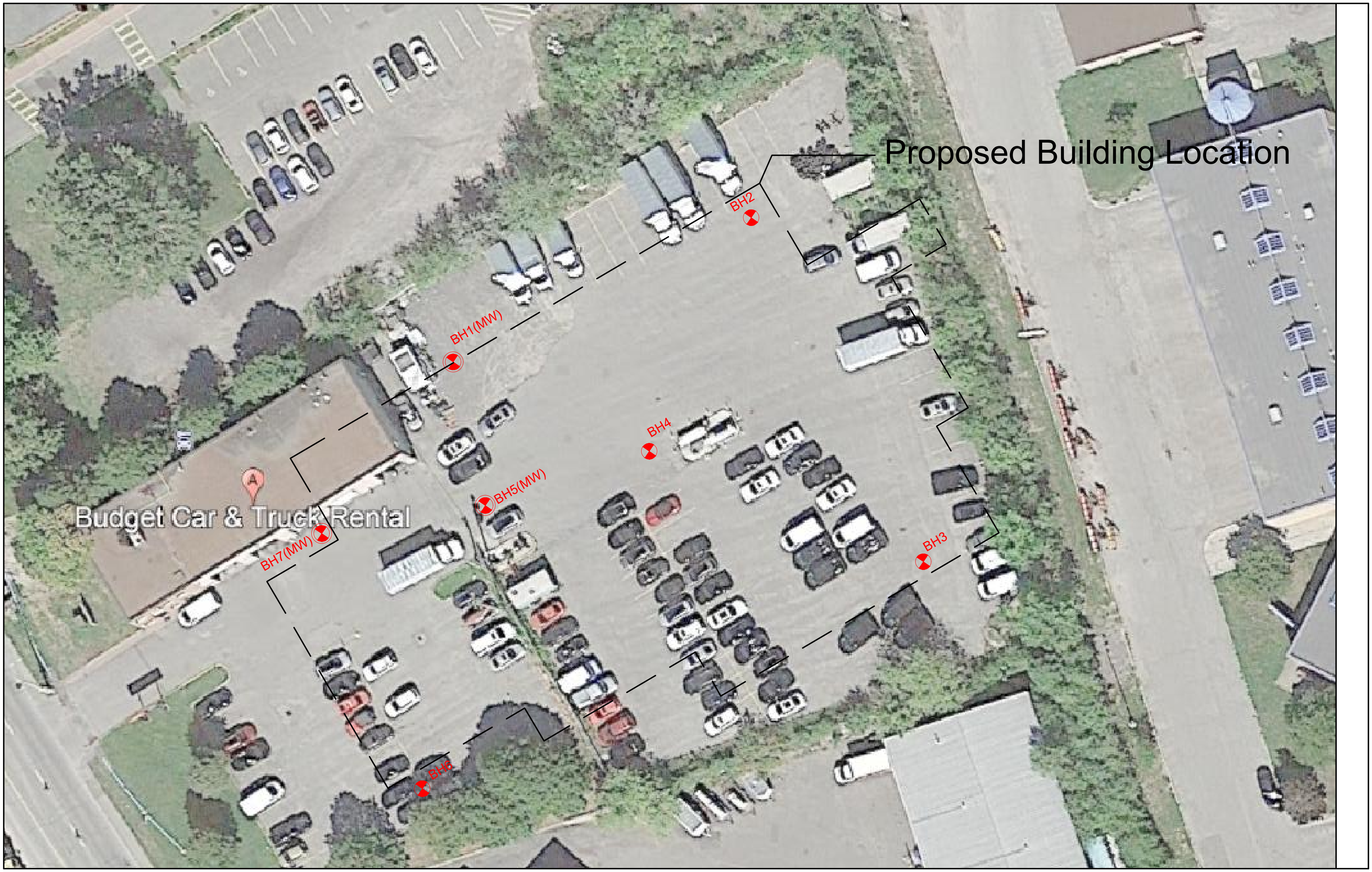
14.0 GENERAL COMMENTS

This report is limited in scope to those items specifically referenced in the text. The discussions and recommendations presented herein are intended only as guidance for the client named and design engineers. The information on which these recommendations are based is subject to confirmation by engineering personnel at the time of construction.

It should also be noted that localized variations in subsoil conditions may be present between and beyond the boreholes investigated and should be verified during construction. As more specific subsurface information becomes available during excavations on the Site, this report should be updated.

Contractors bidding on or undertaking the work should decide on their own investigations, as well as their own interpretations of the factual borehole results. This concern specifically applies to the classification of the subsurface soil and the potential reuse of these soils on/off site. The contractors must draw their own conclusions as to how the near surface and subsurface conditions may affect them.

APPENDIX A – SITE PLAN



Fisher Environmental Ltd.

400 Esna Park Dr., #15
Markham, Ontario
L3R 3K2

Tel: 905 475-7755
Fax: 905 475-7718

KEY PLAN

N

LEGEND

●	Bore Hole Location
◉	Bore Hole With Monitoring Well Location

PROJECT NAME AND ADDRESS

PRELIMINARY
GEOTECHNICAL
INVESTIGATION

851 Industrial Avenue
Ottawa, ON

PROJECT NO.
FE-P 17-8323GEO

DATE
23 AUGUST 2017

SCALE
NTS

FIGURE 2:
Site Plan with Proposed Building Outline

SHEET NO.
3

APPENDIX B – LOG OF BOREHOLES

FISHER
ENVIRONMENTAL LTD.

LOG OF BOREHOLE

NO. BH1(MW) SHEET. 1 of 7

PROJECT NO.: FE-P 17-8323GEO

PROJECT NAME: Prelim Geotechnical Investigation

LOCATION: 851 Industrial Avenue, Ottawa, ON

DRILLING METHOD: D90-Split Spoon

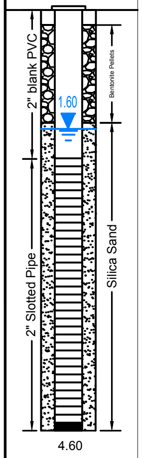
DRILLING DATE: 25 July 2017

SOIL PROFILE			SAMPLES			PENETRATION TESTING (SPT) ▲ 20 40 60 80 / SHEAR STRENGTH (Kpa) ✚ 40 80 120 160	VAPOUR READING (ppm) ☐ 20 40 60 80 / MOISTURE CONTENT (%) ○ 10 20 30 40
DESCRIPTION	STRATA PLOT	ELEV. DEPTH (m)	NUMBER	Type	"N" VALUE		
GROUND SURFACE (m asl)		99.62					
FILL: 100mm of gravel and sand (former tank area).	▨		NO	SAMPLE			
FILL: Sand with gravel, moist, loose to compact. Wet at 1.50m.	▨	98.87/ 0.75	1	SS	14		
			2	SS	10		
			3	SS	6		
Very loose to loose.			4	SS	2		
			5	SS	1		
SILTY SAND: With gravel and clay, dark brown, wet, compact.	▨	95.07/ 4.55	6	SS	11		
			7	SS	11		
CLAY COMPLEX (Weathered shale): Grey, moist, hard (weathered shale).	▨	92.00/ 7.62	8	SS	100+		
End of Borehole		91.54/ 8.08					

DEPTH (feet) 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50

DEPTH (metres) 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

PIEZOMETER OR WELL CONSTRUCTION



Groundwater Depth (m): On 26 July 2017: 1.60m.

LOGGED: SF

CHECKED: CW

FISHER ENVIRONMENTAL LTD.

LOG OF BOREHOLE NO. BH2 SHEET. 2 of 7

PROJECT NO.: FE-P 17-8323GEO

PROJECT NAME: Prelim Geotechnical Investigation

LOCATION: 851 Industrial Avenue, Ottawa, ON

DRILLING METHOD: D90-Split Spoon

DRILLING DATE: 25 July 2017

PENETRATION TESTING (SPT) ▲ 20 40 60 80

SHEAR STRENGTH (Kpa) ✚ 40 80 120 160

VAPOUR READING (ppm) ☐ 20 40 60 80

MOISTURE CONTENT (%) ○ 10 20 30 40

PIEZOMETER OR WELL CONSTRUCTION

SOIL PROFILE		SAMPLES		
DESCRIPTION	ELEV. DEPTH (m)	NUMBER	TYPE	"N" VALUE
GROUND SURFACE (m asl)	98.49			
FILL: 100mm of gravel and sand below 50mm of asphalt.		NO	SAMPLE	
FILL: Silty sand, trace gravel, greyish brown, moist, compact.	97.59/ 0.90	1	SS	16
		2	SS	15
SANDY SILT: Some clay, trace gravel, greyish brown, moist, loose to compact.	96.24/ 2.25	3	SS	5
		4	SS	14
Wet at 4M.		5	SS	14
SILTY SAND AND GRAVEL: Grey, moist, dense.	93.94/ 4.55	6	SS	37
CLAY COMPLEX (Weathered shale): Grey, moist, hard (weathered shale).	92.49/ 6.00	7	SS	100
End of Borehole	91.94/ 6.55			

Groundwater Depth (m): On Completion: 2.13m.

LOGGED: SF

CHECKED: CW

FISHER ENVIRONMENTAL LTD.

LOG OF BOREHOLE

NO. BH3 SHEET. 3 of 7

PROJECT NO.: FE-P 17-8323GEO

PROJECT NAME: Prelim Geotechnical Investigation

LOCATION: 851 Industrial Avenue, Ottawa, ON

DRILLING METHOD: D90– Split Spoon

DRILLING DATE: 25 July 2017

DEPTH (metres)	SOIL PROFILE DESCRIPTION	STRATA PLOT	ELEV. DEPTH (m)	SAMPLES NUMBER	TYPE	"N" VALUE
	GROUND SURFACE (m asl)		98.54			
0	FILL: 100mm of gravel and sand below 50mm of asphalt.		97.79/ 0.75	NO	SAMPLE	
1	FILL: Silty sand with gravel greyish brown, moist, compact.		95.65/ 2.89	1 2 3	SS SS SS	15 15 23
3	SILTY SAND: Dark grey, moist, loose.		94.74/ 3.80	4	SS	9
4	CLAY COMPLEX (Weathered clay): Grey, moist, hard (weathered shale).		93.49/ 5.05	5 6	SS SS	31 48
5	End of Borehole					

PENETRATION TESTING (SPT) ▲ 20 40 60 80

SHEAR STRENGTH (Kpa) ✚ 40 80 120 160

VAPOUR READING (ppm) ☐ 20 40 60 80

MOISTURE CONTENT (%) ○ 10 20 30 40

PIEZOMETER OR WELL CONSTRUCTION

Groundwater Depth (m): On Completion: 1.83m.

LOGGED: SF

CHECKED: CW

FISHER
ENVIRONMENTAL LTD.

LOG OF BOREHOLE

NO. BH4 SHEET. 4 of 7

PROJECT NO.: FE-P 17-8323GEO

PROJECT NAME: Prelim Geotechnical Investigation

LOCATION: 851 Industrial Avenue, Ottawa, ON

DRILLING METHOD: D90 – Split Spoon

DRILLING DATE: 26 July 2017

SOIL PROFILE		SAMPLES			PENETRATION TESTING (SPT) ▲ 20 40 60 80 SHEAR STRENGTH (Kpa) ✚ 40 80 120 160	VAPOUR READING (ppm) ☐ 20 40 60 80 MOISTURE CONTENT (%) ○ 10 20 30 40	PIEZOMETER OR WELL CONSTRUCTION
DESCRIPTION	ELEV. DEPTH (m)	NUMBER	PID	"N" VALUE			
GROUND SURFACE (m asl)	99.02						
FILL: 100mm of gravel and sand below 50mm asphalt. Silty sand, trace gravel, dark grey, moist.	98.27/ 0.75	NO SAMPLE					
	97.82/ 1.20	1	SS	7			
FILL: Silty sand with gravel, trace roots, greyish brown, wet, loose.		2	SS	15			
SILTY SAND/SANDY SILT: With gravel, moist, greyish brown, compact to dense.		3	SS	32			
Some clay.		4	SS	11			
Moist to wet, loose to compact.		5	SS	11			
		6	SS	5			
SANDY SILT TILL AND CLAY COMPLEX (Weathered clay): Dark grey, wet, very dense.	92.92/ 6.10	7	SS	100+			
		8	SS	100+			
WEATHERED SHALE Auger refusal	88.07/ 10.95						
End of Borehole							

Groundwater Depth (m): 3.12m. Caved in at 8.30m.

LOGGED: SF CHECKED: CW

FISHER ENVIRONMENTAL LTD.

LOG OF BOREHOLE

NO. BH5(MW) SHEET. 5 of 7

PROJECT NO.: FE-P 17-8323GEO

PROJECT NAME: Prelim Geotechnical Investigation

LOCATION: 851 Industrial Avenue, Ottawa, ON

DRILLING METHOD: D90 – Split Spoon

DRILLING DATE: 26 July 2017

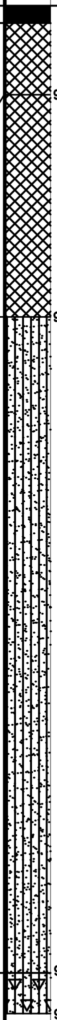
DEPTH (feet)	DEPTH (metres)	SOIL PROFILE DESCRIPTION	ELEV. DEPTH (m)	SAMPLES NUMBER	PID	"N" VALUE
		GROUND SURFACE (m asl)	99.53			
0	0	FILL: 100mm of gravel and sand below 50mm of asphalt.	98.83/ 0.70	NO	SAMPLE	
2–6	1–2	FILL: Silty sand with gravel, dark grey to dark moist, trace weathered grey shale fragments at 760mm, trace coal cinder and rootlets at 1.50m, loose to compact.		1	SS	21
				2	SS	7
8		SILTY SAND: With gravel and clay, dark grey, moist, compact.	97.08/ 2.45	3	SS	16
10	3			4	SS	15
16	5			5	SS	17
20–22	6–7	Water seam between 6.40m–6.70m.		6	SS	15
25–26	7.60–8	SILTY SAND WITH GRAVEL: With weathered shale, dark grey, moist to wet, very dense.	91.93/ 7.60	7	SS	71
		End of Borehole	91.63/ 7.90			

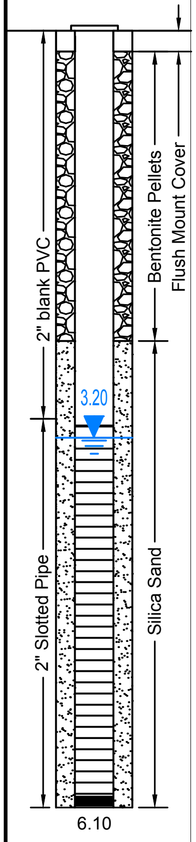
PENETRATION TESTING (SPT) ▲ 20 40 60 80

SHEAR STRENGTH (Kpa) ✚ 40 80 120 160

VAPOUR READING (ppm) ☐ 20 40 60 80

MOISTURE CONTENT (%) ○ 10 20 30 40





Groundwater Depth (m): On 26 July 2017: 3.20m.

LOGGED: SF

CHECKED: CW

FISHER ENVIRONMENTAL LTD.

LOG OF BOREHOLE

NO. BH6 SHEET. 6 of 7

PROJECT NO.: FE-P 17-8323GEO

PROJECT NAME: Prelim Geotechnical Investigation

LOCATION: 851 Industrial Avenue, Ottawa, ON

DRILLING METHOD: D90 – Split Spoon

DRILLING DATE: 26 July 2017

DEPTH (feet): 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

DEPTH (metres): 0 1 2 3 4 5 6 7 8 9 10

SOIL PROFILE			SAMPLES			PENETRATION TESTING (SPT) ▲ 20 40 60 80 SHEAR STRENGTH (Kpa) ✚ 40 80 120 160	VAPOUR READING (ppm) ☐ 20 40 60 80 MOISTURE CONTENT (%) ○ 10 20 30 40	PIEZOMETER OR WELL CONSTRUCTION
DESCRIPTION	STRATA PLOT	ELEV. DEPTH (m)	NUMBER	PID	"N" VALUE			
GROUND SURFACE (m asl)		99.55						
FILL: 100mm of sand and gravel below 50mm of asphalt.			NO SAMPLE					
FILL: Silty sand, some clay, greyish brown, moist.		98.85/ 0.70	1 2	SS SS	18 32			
SILTY SAND: With gravel, some clay, greyish brown, moist to wet.		97.25/ 2.30	3 4	SS SS	19 11			
SILTY SAND AND SANDY SILT: With clay complex / weathered shale and gravel, dark grey, moist to wet.		94.95/ 4.60	5 6	SS SS	29 34			
End of Borehole		93.00/ 6.55						

Groundwater Depth (m): On Completion: Dry.

LOGGED: SF

CHECKED: CW

FISHER ENVIRONMENTAL LTD.

LOG OF BOREHOLE NO. BH7 SHEET. 7 of 7

PROJECT NO.: FE-P 17-8323GEO

PROJECT NAME: Prelim Geotechnical Investigation

LOCATION: 851 Industrial Avenue, Ottawa, ON

DRILLING METHOD: D90 – Split Spoon

DRILLING DATE: 26 July 2017

SOIL PROFILE DESCRIPTION	STRATA PLOT	ELEV. DEPTH (m)	SAMPLES NUMBER	PID	"N" VALUE
GROUND SURFACE (m asl)		99.87			
FILL: 100mm of sand and gravel below 75mm of asphalt.			NO SAMPLE		
FILL: Silty sand with gravel, trace asphalt, brown, moist, some organics and compact.		99.12/ 0.75	1	0.2	15
			2	0	12
SILTY SAND: With gravel, greyish brown, moist, compact.		97.62/ 2.25	3	0	25
			4	0	23
Some clay.			5	0	12
SILTY SAND: Some coarse sand, grey, wet, compact.		93.77/ 6.10	6	1.3	12
COMPLEX CLAY: Weathered shale, coarse sand and silty clay seams, grey, wet, very dense.		92.26/ 7.61	7	0	62
			8	0	100+
End of Borehole		90.24/ 9.63			

PENETRATION TESTING (SPT) ▲ 20 40 60 80

SHEAR STRENGTH (Kpa) ✚ 40 80 120 160

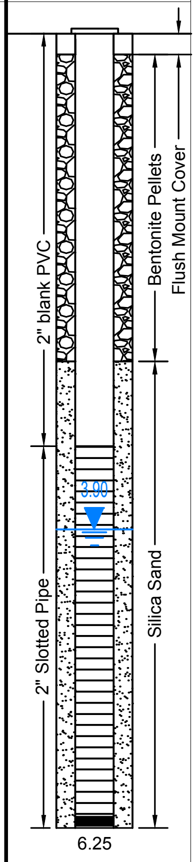
VAPOUR READING (ppm) ☐ 20 40 60 80

MOISTURE CONTENT (%) ○ 10 20 30 40

DEPTH (feet) 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

DEPTH (metres) 0 1 2 3 4 5 6 7 8 9 10

PIEZOMETER OR WELL CONSTRUCTION



Groundwater Depth (m): On 26 July 2017: 3.90m.

LOGGED: SF

CHECKED: CW

APPENDIX C– MOISTURE CONTENT AND GRAIN SIZE DISTRIBUTION ANALYSIS

FISHER ENVIRONMENTAL LABORATORIES
FULL RANGE ANALYTICAL SERVICES • SOIL/WATER/AIR TESTING • ENVIRONMENTAL
COMPLIANCE PACKAGES • 24 HOUR EMERGENCY RESPONSE • CALA ACCREDITED
400 ESNA PARK DRIVE #15
MARKHAM, ONT. L3R 3K2
TEL: 905 475-7755
FAX: 905 475-7718
www.fisherenvironmental.com

Client: Dymon Capital Corp
Address: 2-1830 Walkley Rd.
Ottawa, Ontario
K1H 8K3
Tel.:
E-mail:
Attn.: Bliss Edwards

F.E. Job #: 17-7048
Project Name: Hydrogeological Investigation
Project ID: FE-P-17-8323
Date Sampled: N/A
Date Received: 30-Aug-17
Date Reported: 6-Sep-17
Location: 851 Industrial Avenue
Toronto, ON

Certificate of Analysis

Analyses	Matrix	Quantity	Date Extracted	Date Analyzed	Lab SOP	Method Reference
Moisture Content	Soil	9	N/A	6-Sep-17	Support Procedures F-99	Carter (1993)
Grain Size	Soil	6	N/A	6-Sep-17	Grain Size F-28	ASTM D6913-04

Fisher Environmental Laboratories is accredited by CALA (the Canadian Association for Laboratory Accreditation Inc.) for specific parameters as required by Ontario Regulation 153/04. All analytical testing has been performed in accordance with ISO 17025 and the Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act published by Ontario Ministry of the Environment.

Authorized by: Lin Rong
Roger Lin, Ph. D., C. Chem.
Laboratory Manager

ASSOCIATION OF THE CHEMICAL PROFESSION OF ONTARIO
CHARTERED
Ronggen (Roger) Lin
CHEMIST

Certificate of Analysis

Analysis Requested:	Moisture Content, Grain Size
Sample Description:	9 Soil Samples

Parameter	***17-7048-1*** BH1 SS2	***17-7048-2*** BH1 SS3	***17-7048-3*** BH1 SS4	***17-7048-4*** BH1 SS5	***17-7048-5*** BH3 SS2	***17-7048-6*** BH3 SS3
Moisture Content (%)	13.1	20.6	24.0	26.3	16.0	7.7

Parameter	***17-7048-7*** BH4 SS2	***17-7048-8*** BH4 SS3	***17-7048-9*** BH4 SS4			
Moisture Content (%)	8.5	9.9	8.0			

QA/QC Report

Parameter	**Blank**	**RL**	**LCS**	**AR**	**Duplicate**	**AR**
			Recovery (%)		**RPD (%)**	
Moisture Content (%)	<0.1	0.1	100	70-130	5.6	0-20

LEGEND:

RL - Reporting Limit
LCS - Laboratory Control Sample
AR - Acceptable Range
RPD - Relative Percent Difference

Certificate of Analysis

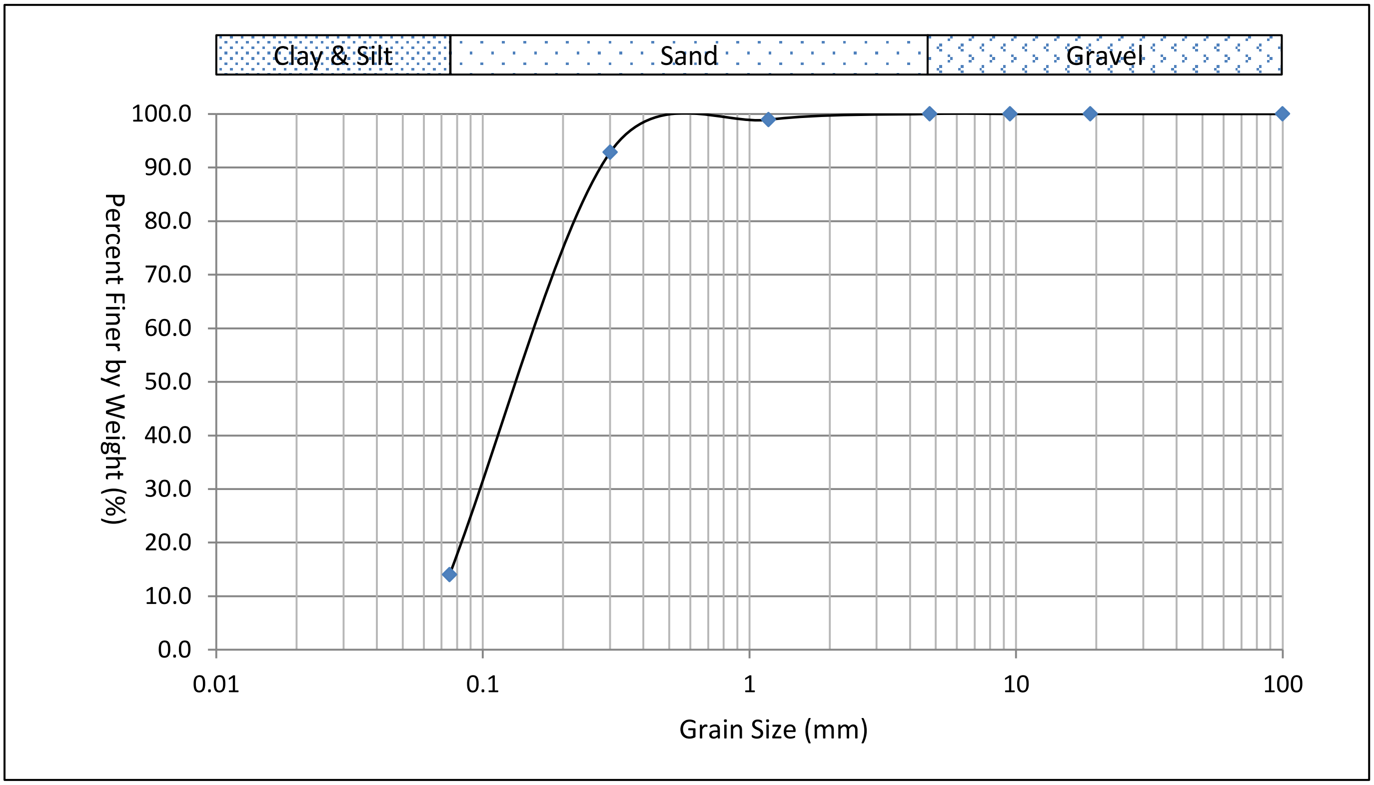
Analysis Requested:	Moisture Content, Grain Size
Sample Description:	9 Soil Samples

Parameter	***17-7048-3*** BH1 SS4	***17-7048-4*** BH1 SS5	***17-7048-6*** BH3 SS3	***17-7048-7*** BH4 SS2	***17-7048-8*** BH4 SS3	***17-7048-9*** BH4 SS4
Grain Size (%)						
>19mm	0.0	0.0	0.0	0.0	0.0	0.0
9.5mm-19mm	0.0	0.0	0.0	0.0	0.0	0.0
4.75mm-9.5mm	0.0	0.0	15.1	17.6	7.7	5.7
1.18mm-4.75mm	1.1	8.6	26.3	12.7	9.8	17.5
	6.1	6.4	13.1	14.3	14.6	18.9
75um-300um	78.8	75.4	15.2	19.0	19.0	19.6
<75um	14.0	9.6	30.4	36.4	48.9	38.3
Clay & Silt	**14**	**10**	**30**	**36**	**49**	**38**
Sand	**86**	**90**	**55**	**46**	**43**	**56**
Gravel	**0**	**0**	**15**	**18**	**8**	**6**

Grain Size Distribution

Sample ID: 17-7048-3, BH1, SS4

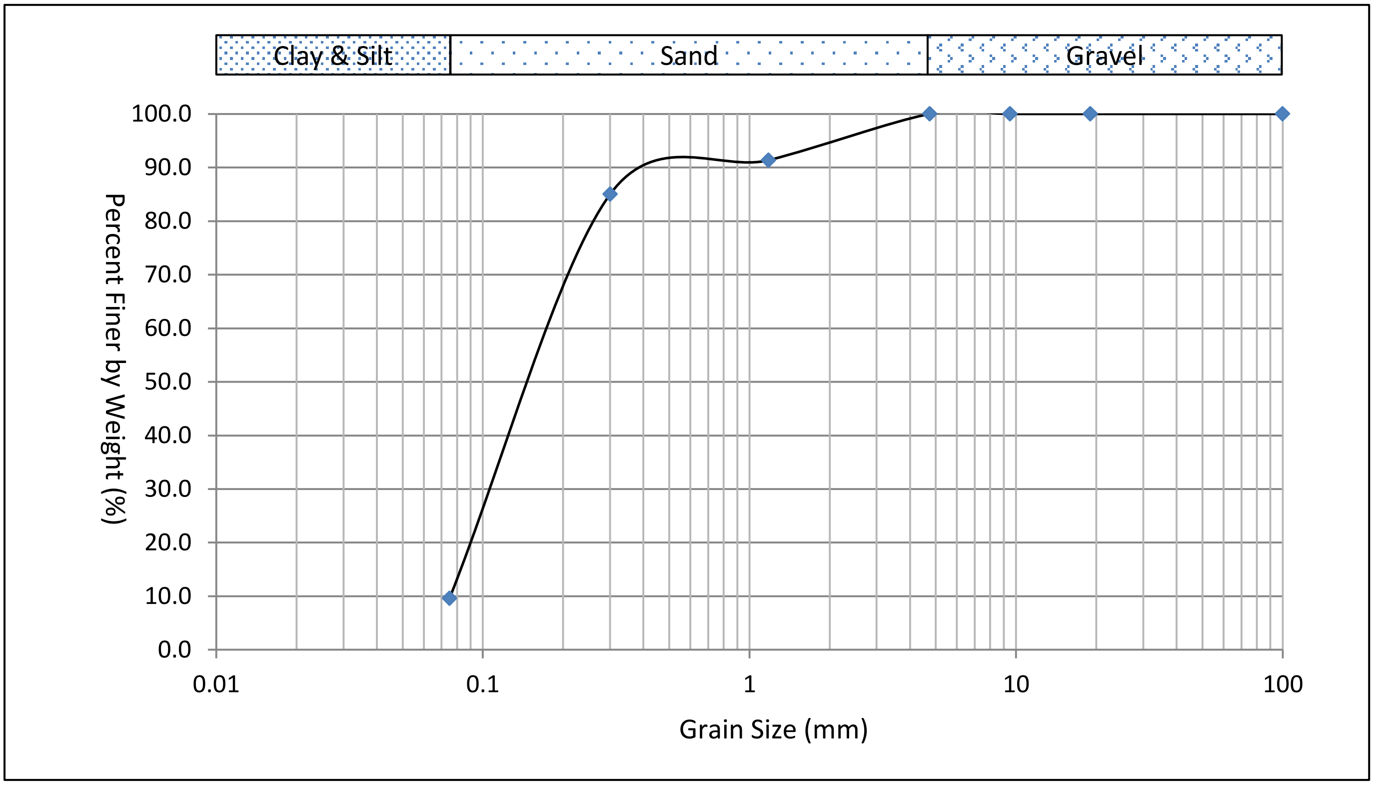
Clay & Silt 14%, Sand 86%, Gravel 0%



Grain Size Distribution

Sample ID: 17-7048-4, BH1, SS5

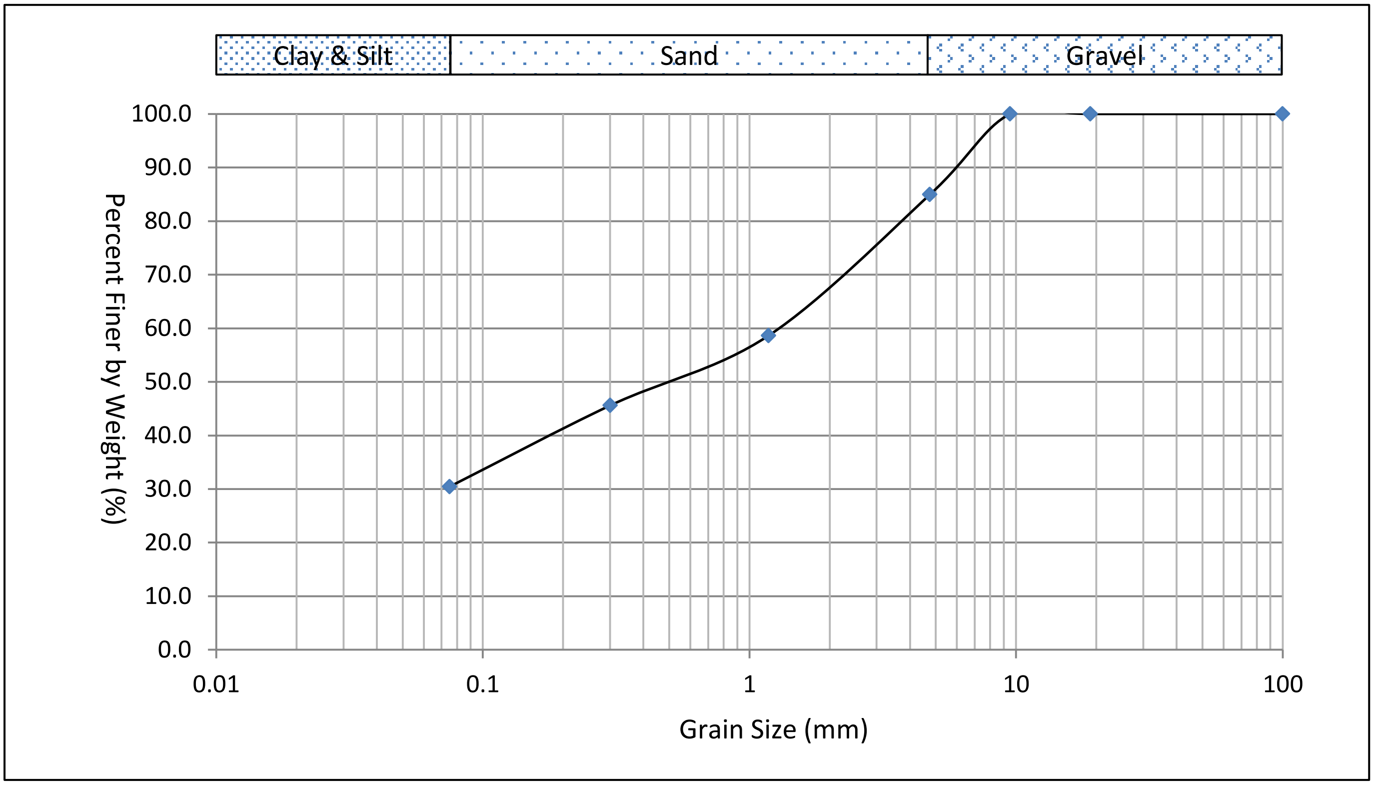
Clay & Silt 10%, Sand 90%, Gravel 0%



Grain Size Distribution

Sample ID: 17-7048-6, BH3, SS3

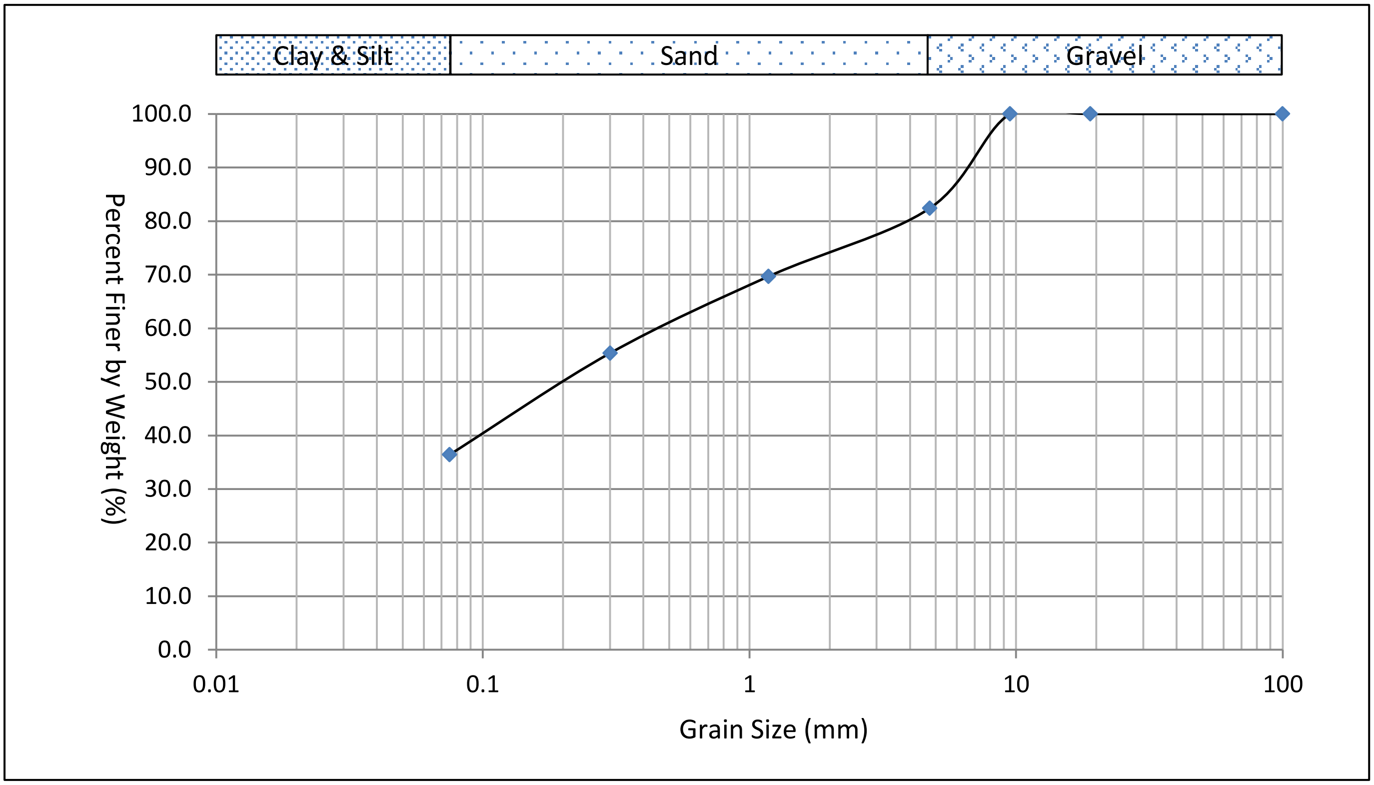
Clay & Silt 30%, Sand 55%, Gravel 15%



Grain Size Distribution

Sample ID: 17-7048-7, BH4, SS2

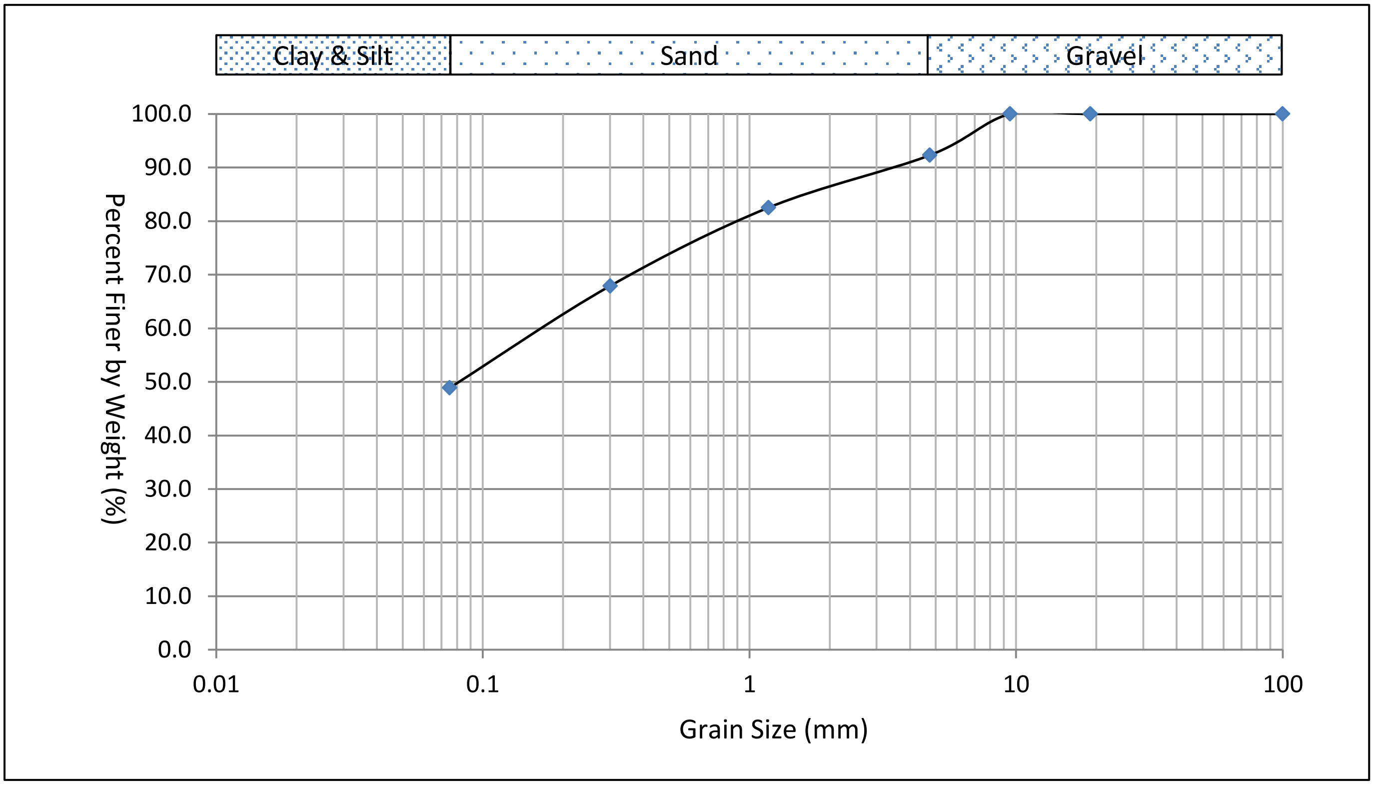
Clay & Silt 36%, Sand 46%, Gravel 18%



Grain Size Distribution

Sample ID: 17-7048-8, BH4, SS3

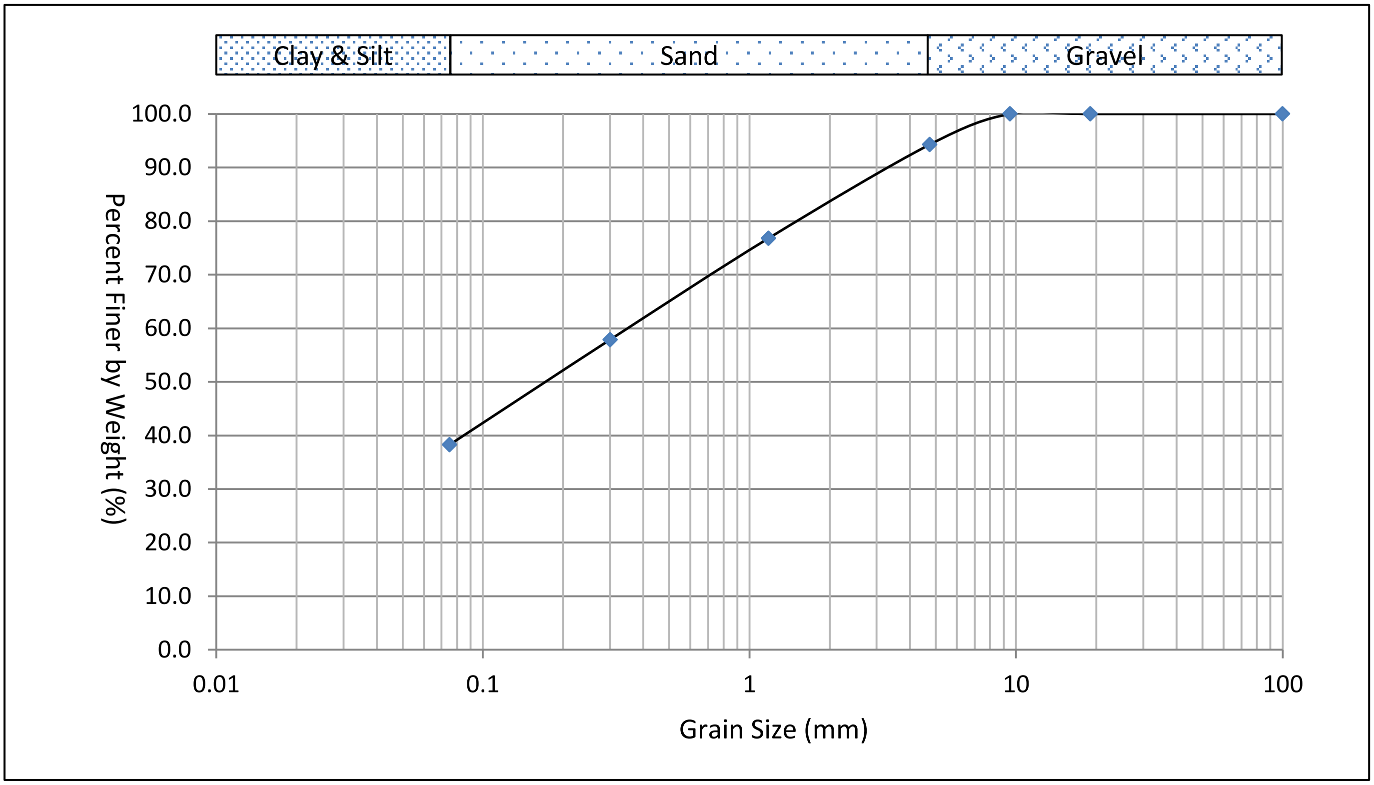
Clay & Silt 49%, Sand 43%, Gravel 8%



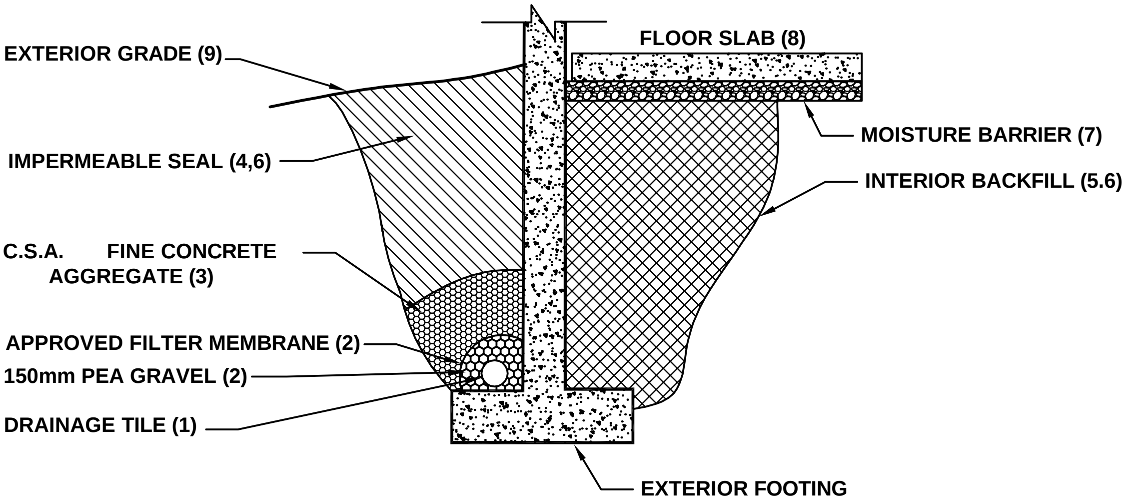
Grain Size Distribution

Sample ID: 17-7048-9, BH4, SS4

Clay & Silt 38%, Sand 56%, Gravel 6%



APPENDIX D – DRAINAGE AND BACKFILL RECOMMENDATIONS



NOTES:

(1) DRAINAGE TILE TO CONSIST OF 100mm (4") DIAMETER WEEPING TILE OR EQUIVALENT PERFORATED PIPE LEADING TO A POSITIVE SUMP OR OUTLET. INVERT TO BE A MINIMUM OF 150MM (6") BELOW UNDERSIDE OF FLOOR SLAB.

(2) PEA GRAVEL-150mm (6") TOP AND SIDE OF DRAIN. IF DRAIN IS NOT ON FOOTING, PLACE 100mm (4") OF PEA GRAVEL BELOW DRAIN. 20mm (3/4") CLEAR STONE IS AN ALTERNATIVE PROVIDED IT IS SURROUNDED BY AN APPROVED FILTER FABRIC (TERRAFIX 270R OR EQUIVALENT).

(3) C.S.A. FINE CONCRETE AGGREGATE TO ACT AS FILTER MATERIAL. MINIMUM 300mm (12") TOP AND SIDE OF TILE DRAIN. THIS MAY BE REPLACED BY AN APPROVED FILTER FABRIC AS INDICATED IN (2).

(4) IMPERMEABLE BACKFILL SEAL - COMPACTED CLAY, CLAYEY SILT OR EQUIVALENT. IF ORIGINAL SOIL IS FREE-DRAINING, SEAL MAY BE OMITTED.

(5) THE ENTIRE FILL MAY BE ANY CLEAN NON-ORGANIC SOIL WHICH CAN BE COMPACTED TO THE SPECIFIED IN THIS CONFINED SPACE.

(6) DO NOT USE HEAVY COMPACTION EQUIPMENT WITHIN 450mm (18") OF THE WALL. DO NOT FILL OR COMPACT WITHIN 1.8m(6') OF THE WALL UNLESS FILL IS PLACED ON BOTH SIDES SIMULTANEOUSLY.

(7) MOISTURE BARRIER TO BE AT LEAST 200mm (8") OF COMPACTED CLEAR 20mm (3/4") STONE.

(8) SLAB ON GRADE SHOULD NOT BE STRUCTURALLY CONNECTED TO THE WALL OR FOOTING.

(9) EXTERIOR GRADE TO SLOPE AWAY FROM BUILDING.

(10) THIS SYSTEM IS NOT NORMALLY REQUIRED IF THE FLOOR SLAB IS AT LEAST 300mm (1') ABOVE THE EXTERIOR GRADE.

DRAINAGE AND BACKFILL RECOMMENDATIONS

FOR SLAB ON GRADE CONSTRUCTION

(NOT TO SCALE)

APPENDIX E – SHEAR-WAVE VELOCITY SOUNDING

GEOPHYSICS GPR INTERNATIONAL INC.

100 – 2545 Delorimier Street
Longueuil (Québec)
Canada J4K 3P7

Tel. : (450) 679-2400
Fax : (514) 521-4128
info@geophysicsgpr.com
www.geophysicsgpr.com

August 22nd, 2017 Transmitted by email: Sean@fisherenvironmental.com

Our Ref.: M-17561

Mr. Sean Fisher, M.Sc.
Project Manager
Fisher Environmental Ltd.
400 Esna Park Dr #15
Markham (ON) L3R 3K2

Subject: **Shear-Wave Velocity Sounding, 851 Industrial Avenue, Ottawa (ON)**

Dear Sir,

Geophysics GPR International Inc. has been requested by Fisher Environmental Ltd. to carry out seismic shear wave surveys at 851 Industrial Avenue, in Ottawa (ON). The geophysical investigations used the Multi-channel Analysis of Surface Waves (MASW), the Extended SPatial AutoCorrelation (ESPAC) and the seismic refraction method as complement. From the subsequent results, the $\overline{V}_{S30}$ value was calculated to identify the Site Class.

The surveys were carried out August 15th, by Mr. Alexis Marchand and Mrs. Delphine Leroux. The Figure 1 shows the regional location of the site and the Figure 2 illustrates the location of the seismic spreads. Both figures are presented in Appendix.

The following paragraphs briefly describe the survey design, the principles of the test methods, and the results in graphic and table format.

METHODS PRINCIPLES

MASW

The *Multi-channel Analysis of Surface Waves* (MASW) and the *Extended SPatial AutoCorrelation* (ESPAC or MAM for *Microtremors Array Method*) are seismic methods used to evaluate the shear wave velocities of subsurface materials through the analysis of the dispersion properties of the Rayleigh surface waves ("ground roll"). The MASW is considered an "active" method, as the seismic signal is induced at known location and time in the geophones spread axis. Conversely, the ESPAC is considered a "passive" method, using the low frequency "noises" produced far away. The method can also be used with "active" seismic source records. The ESPAC method allows deeper Vs soundings, but generally with a lower resolution for the surface portion. Its dispersion curve can then be merged with the higher frequency one from the MASW to calculate a more complete inversion. The dispersion properties are measured as a change in phase velocity with frequency. Surface wave energy will decay exponentially with depth. Lower frequency surface waves will travel deeper and thus be more influenced by deeper velocity layering than the shallow higher frequency waves. The inversion of the Rayleigh wave dispersion curve yields a shear wave (V_S) velocity depth profile (sounding). Figure 3 outlines the basic field operating procedure for the MASW method.

Figure 4 illustrates an example of one of the MASW/ESPAC records, the corresponding spectrogram analysis and resulting 1D V_S model.

Seismic Refraction

The method consists in measuring the propagation delays of the direct and refracted seismic waves (P and/or S) produced by an artificial source in the axis of a seismic spread. The seismic velocities of the materials can be directly calculated, then the refractors depths.

More detailed descriptions of the methods are presented in *Shear Wave Velocity Measurement Guidelines for Canadian Seismic Site Characterization in Soil and Rock*, Hunter, J.A., Crow, H.L., et al., Geological Surveys of Canada, General Information Product 110, 2015.

INTERPRETATION METHODS

MASW surveys

The main processing sequence involved data inspection; spectral analysis (“phase shift” for MASW, and cross-correlation for ESPAC); picking the fundamental mode of the dispersion curves; and 1D modelling and inversion of the MASW and ESPAC shot records using the SeisImagerSW™ software. The data modeling and inversions used a non-linear least square algorithm.

In theory, all the shot records for a given seismic spread should produce a similar shear-wave velocity profile. In practice, however, differences can arise due to energy dissipation, localized surface seismic velocities variations, and/or dipping of overburden layers or rock. In general the precision of the calculated seismic shear wave velocities (V_S) is of the order of 15% or better.

Seismic Refraction surveys

The considered seismic wave’s arrival times were identified for each geophone. The General Reciprocal Method was used, with signal sources at both ends of the seismic spread, in order to consider seismic wave propagation for two opposite directions. The records were realised to calculate the rock depth, and its seismic velocity. Conversely to the MASW method, the seismic rock velocity measured by seismic refraction is only representative of its superior part, due to the evanescent nature of the refracted wave. The rock seismic velocities were calculated using two methods: the reduced travel-times (the Hobson and Overton method) and the opposite apparent velocities. The first one allows independence from the surface and rock topography effect, as well as the overburden lateral variation of its seismic velocity, but remains limited to common geophones. Its application remains however limited to shallow to intermediate depths refractors. The second one can use longer segments of opposite directions signals, improving the linear regressions accuracy, but remains affected by the surface and rock topography effect, as well as the overburden lateral variation of the seismic velocity.

SURVEY DESIGN

The seismic sounding was realised on a parking lot located west-north-west of the intersection of Industrial Avenue and St-Laurence Blvd. The geophone spacing for the main spread was of 3 metres, which means that the total length of a 24 geophones spread was 69 metres. A second shorter seismic spread, with geophone spacing of 1 metre, was dedicated to the near surface materials.

The shear wave depth soundings can be considered as the average of the bulk area within the geophone spread, especially for its central half-length.

The seismic records were realized with a seismograph Terraloc MK6 (from ABEM Instrument), and the geophones were 4.5 Hz. An 18 pounds sledgehammer was used as the energy source with impacts being recorded off both ends of the seismic spreads.

The seismic records counted 4096 data, sampled at 1000 µs for the MASW, and 50 µs for the seismic refraction method. The records included a pre-trig portion of 10 ms. A stacking procedure was also used to improve the Signal / Noise ratio for the seismic records.

RESULTS

From seismic refraction the rock was calculated between 5 metres and 6 metres deep, with an average depth of 5.4 metres (± 1 metre). The shallow rock shear wave velocity value was calculated around 1575 to 1625 m/s (cf. Fig. 5). These results were used to build the geophysical models, prior to the models and inversions calculations.

The MASW V_{SV} calculated results are illustrated at Figure 6, and they are also presented at the Table 1.

The $\overline{V}_{S30}$ value results from the harmonic mean of the shear wave velocities, from the surface to 30 metres deep. It is calculated by dividing the total depth of interest (30 metres) by the sum of the time spent in each velocity layer from the surface up to 30 metres. This value reflects an equivalent homogeneous single layer response.

The calculated $\overline{V}_{S30}$ value for the actual site is 896.3 m/s, corresponding to the Site Class “B”. However, the Site Classes A and B are not to be used if there is more than 3 metres of unconsolidated materials between the rock surface and the bottom of the spread footing or the mat foundation.

CONCLUSION

Seismic surveys were carried out with the MASW and ESPAC analysis methods, as well as the seismic refraction method to calculate the $\overline{V}_{S30}$ value for the Site Class determination. The surveyed site was located at 851 Industrial Avenue, in Ottawa (ON).

The $\overline{V}_{S30}$ value of the actual site is 896 m/s. Considering this value (determined through the MASW, the ESPAC and the seismic refraction methods), Table 4.1.8.4.A of the CNBC, and the Building Code, O. Reg. 332/12, the investigated site presents a site class “B” ($760 < \overline{V}_{S30} \leqslant 1500$ m/s). Nevertheless, seismic refraction results presented rock depths between 5 and 6 metres deep (± 1 metre). According to the Building Code, the Site Classes A and B are not to be used if there is more than 3 metres of unconsolidated materials between the rock surface and the bottom of the spread footing or the mat foundation.

It must be noted that other geotechnical information gleaned on site; including the presence of liquefiable soils, soft clays, high moisture content etc. can supersede the Site Classification provided in this report based on the $\overline{V}_{S30}$ value.

The V_{SV} values calculated are representative of the in situ materials, and were not corrected for the total and effective stresses.

Jean-Luc Arsenault, M.A.Sc., P.Eng.
Project Manager

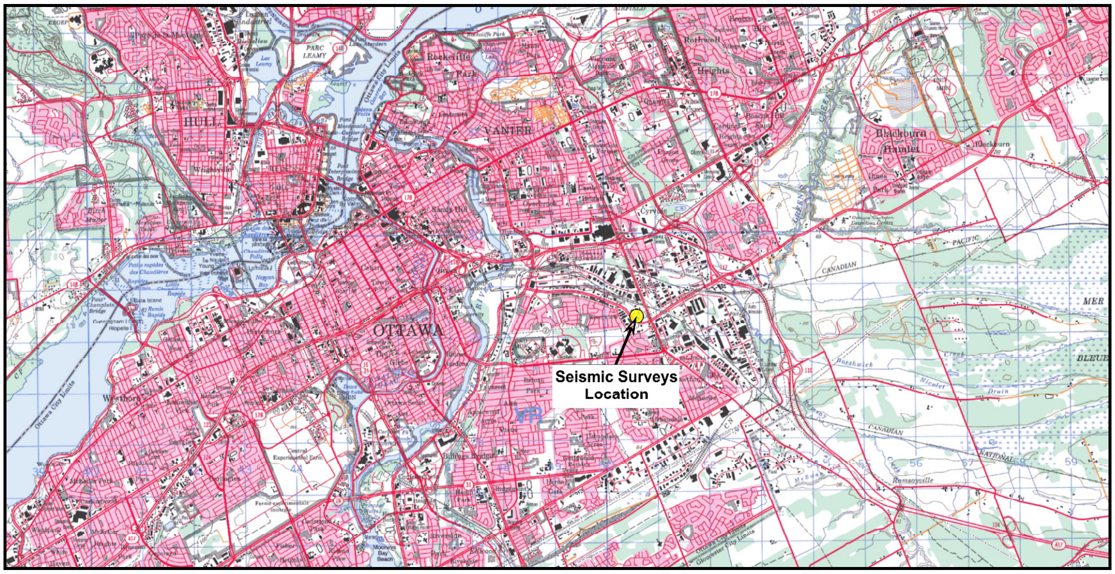


Figure 1: Regional location of the Site
(source: topographic map 31 G/05)

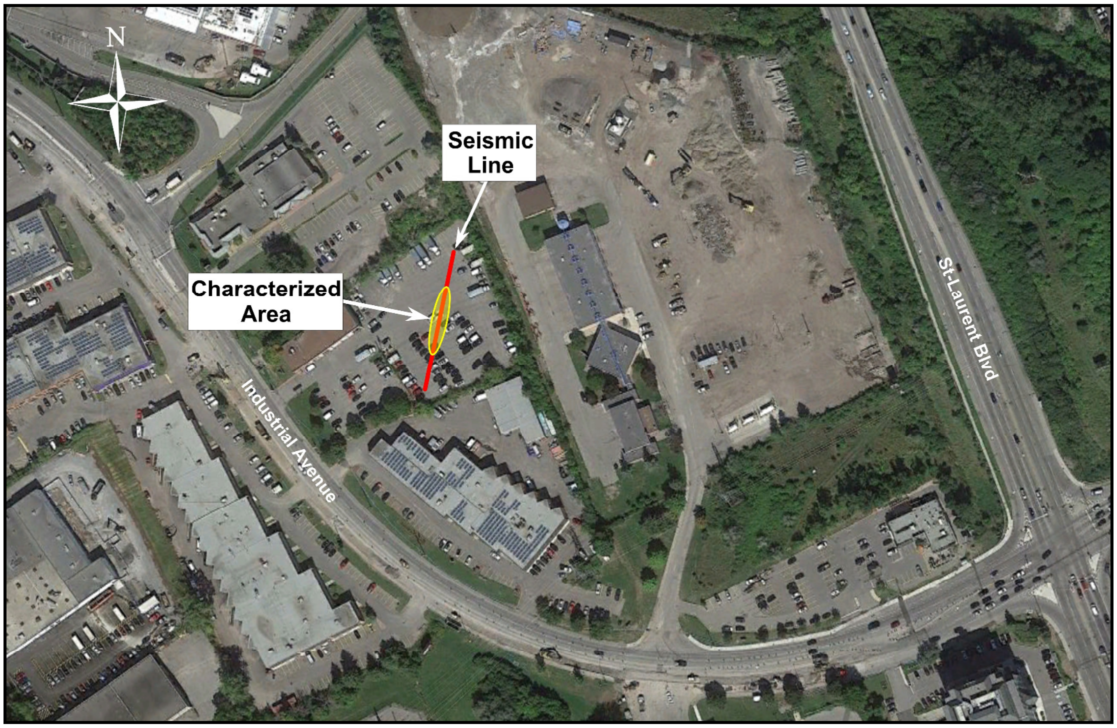


Figure 2: Location of the seismic spreads
(source : *Google Earth*™)

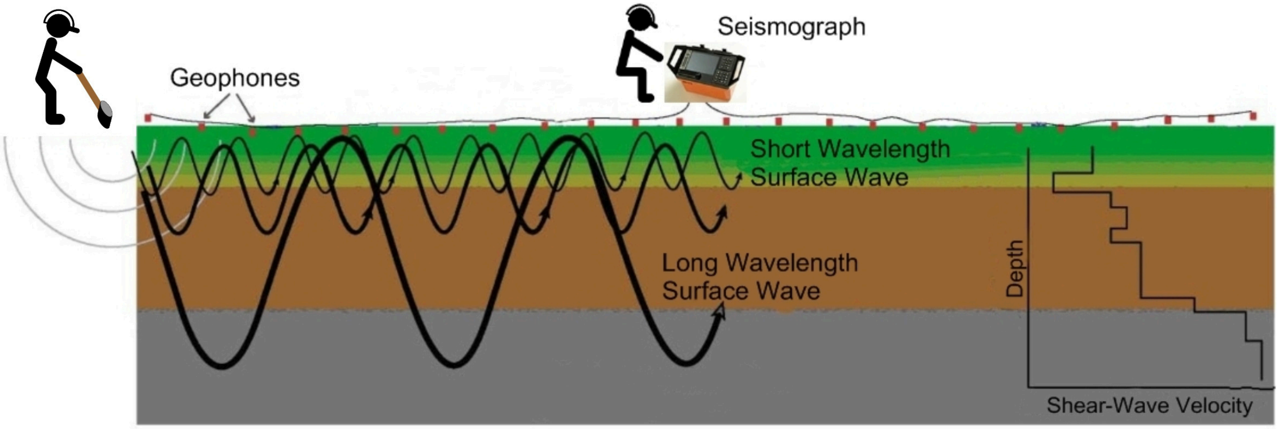
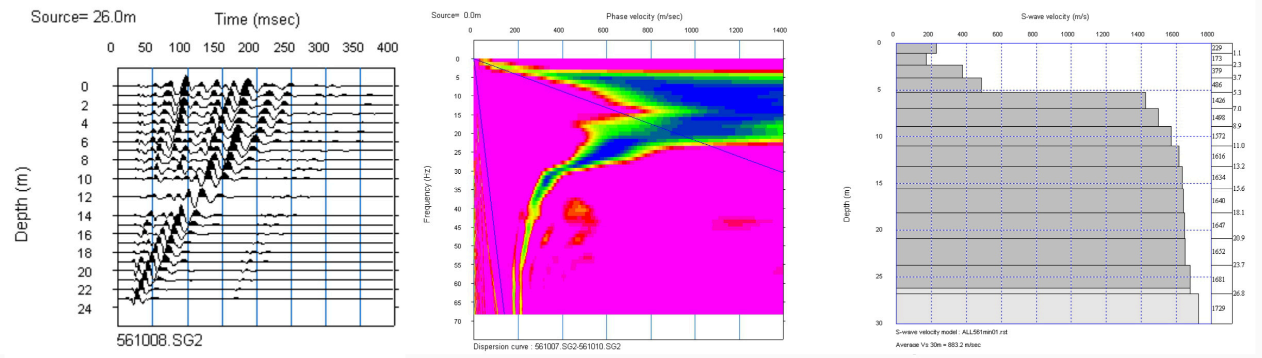


Figure 3: MASW Field Operating Principle



Raw Seismic Shot Record

Phase Velocity-Frequency Transformation indicating Dispersion Curve

1D Shear-Wave Velocity Profile from Inversion of Dispersion Curve

Figure 4: Example of a MASW/ESPAC Record, Phase Velocity - Frequency Curve and resulting 1D Shear Wave Velocity Model

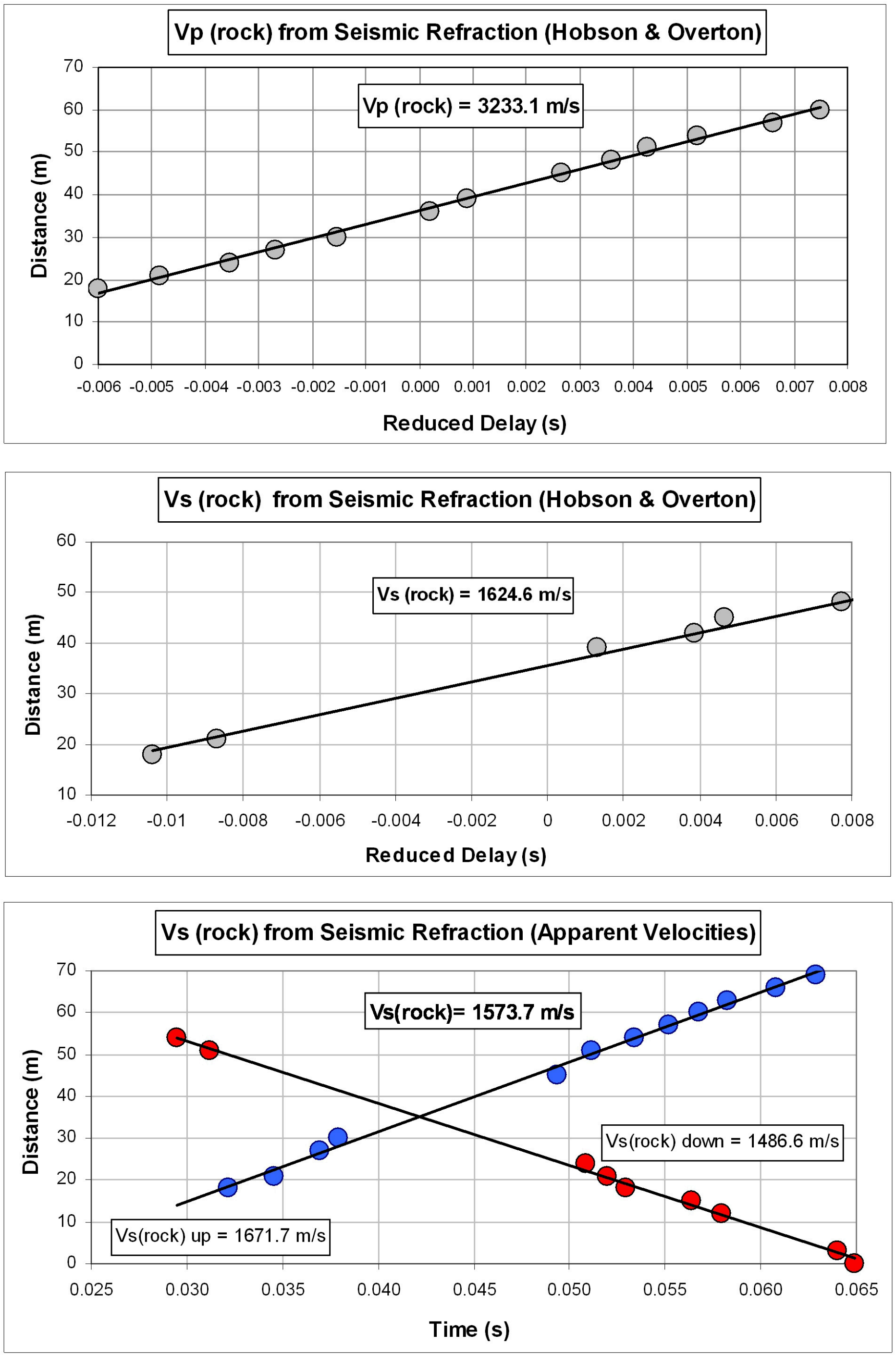


Figure 5: Seismic Refraction Vs Calculation

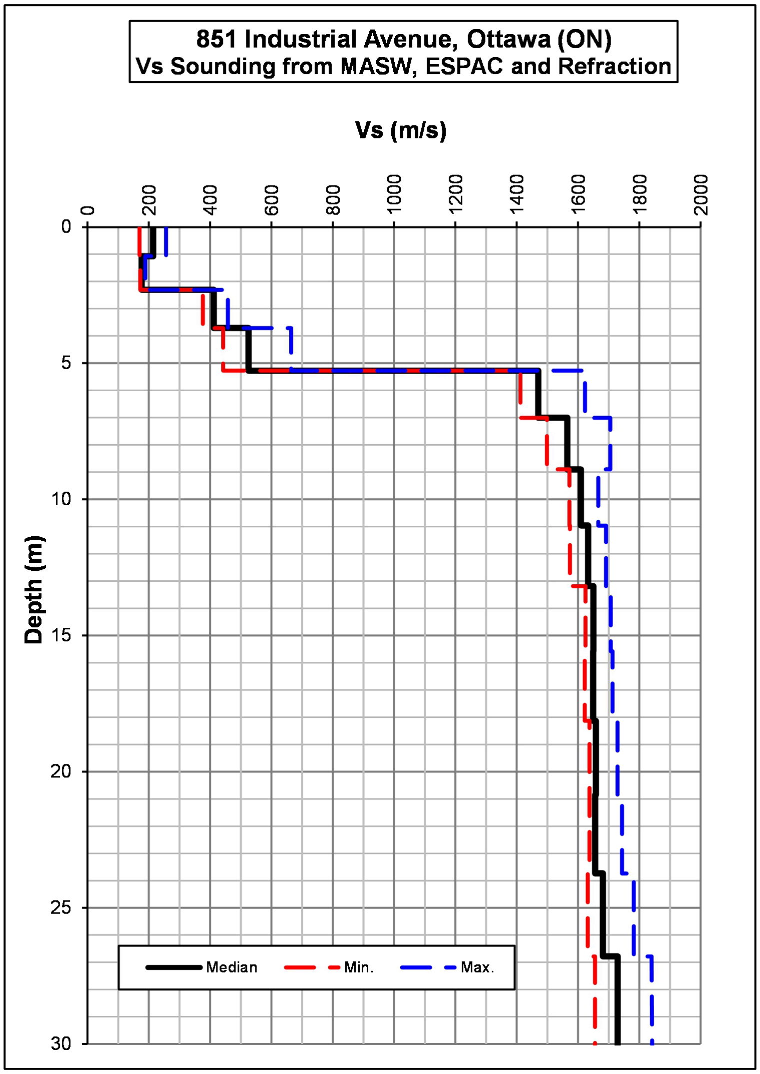


Figure 6: Vs Sounding from MASW, ESPAC and Refraction

TABLE 1

V_{S30} Calculation for the Site Class (actual site)

Depth	Vs			Thickness	Cumulative Thickness	Delay for Med. Vs	Cumulative Delay	Avg. Vs at given Depth
	Min.	Median	Max.					
(m)	(m/s)	(m/s)	(m/s)	(m)	(m)	(s)	(s)	(m/s)
0	170.0	214.4	256.2					
1.07	172.3	176.6	188.3	1.07	1.07	0.004995	0.004995	214.4
2.31	376.0	411.4	457.9	1.24	2.31	0.007000	0.011995	192.3
3.71	442.4	524.7	664.7	1.40	3.71	0.003406	0.015400	240.8
5.27	1411.9	1470.2	1622.5	1.57	5.27	0.002984	0.018385	286.9
7.01	1499.0	1564.8	1704.7	1.73	7.01	0.001177	0.019562	358.1
8.90	1572.3	1608.8	1666.0	1.90	8.90	0.001212	0.020774	428.5
10.96	1573.7	1632.5	1691.1	2.06	10.96	0.001280	0.022054	497.0
13.19	1624.6	1650.0	1707.0	2.23	13.19	0.001363	0.023417	563.1
15.58	1622.2	1649.5	1712.3	2.39	15.58	0.001448	0.024866	626.4
18.13	1637.0	1658.2	1728.4	2.56	18.13	0.001549	0.026415	686.4
20.85	1637.0	1655.4	1743.2	2.72	20.85	0.001640	0.028055	743.2
23.74	1631.5	1681.2	1781.5	2.89	23.74	0.001743	0.029798	796.6
26.79	1655.6	1729.1	1839.5	3.05	26.79	0.001814	0.031611	847.3
30.00	1655.6	1729.1	1839.5	3.21	30.00	0.001859	0.033471	896.3

V_{S30} (m/s)	**896.3**
Site Class	**B ***

* : The Site Classes “A” and “B” are not to be used if there is more than 3 metres of unconsolidated material between the rock surface and the lower portion of the foundations.