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August 13, 2021

Mr. Pierre Courteau
Consolidated Fastfrate (Ottawa) Holdings Inc.
55 Commerce Valley Drive West
Suite 220
Thornhill, ON L3T 7V9

Slope stability assessment for dynamic compaction - Warehouse and offices
Intersection of Rideau Road and Somme Street, Ottawa, ON
Issued for Site Plan Application

Dear Mr. Courteau:

1. Introduction

Consolidated Fastfrate (Ottawa) Holdings Inc. (Fastfrate) has requested GHD Limited (GHD) to perform a slope stability assessment for the slopes along Rideau Road and Somme Street (Site) in preparation for the dynamic compaction works. The location of the Site is shown on the site layout in Figure 1.1.

The Site is located at the intersection of Rideau Road to the north and Somme Street to the west and is relatively flat and is covered with approximately six (6) metres thick fill, reportedly brought in from construction sites, which gives the Site its present flat surface albeit slightly hummocky look, sloping down to the surrounding streets. The surrounding topography slopes up at approximately two-horizontal to one-vertical (2H:1V) from south to north by approximately 3.5 meters from Rideau Road to the section of Somme Street south of the Site. The Site elevation is higher compared to the surrounding streets varying from approximately 0.2 metres higher on the south side (Somme Street) to four metres higher on the north side (Rideau Street). There is also a ditch along the south, west, and north perimeters of the Site.

Fastfrate is proposing to develop an approximately 8,630 square meters (sqm) warehouse on the western portion of the Site. It is GHD's understanding that Fastfrate intends to use dynamic compaction method of ground improvement to densify the randomly placed fill materials prior to the proposed development.

The stability assessment has been completed in alignment with the cross-sections received by GHD from CIVITAS and CIMA+ on July 28, 2021, and July 22, 2021, respectively, which outlined retaining walls for the north and west slopes. The locations of the cross-sections are shown on the site plan provided in Figure 1.1 Site layout.

GHD understands that the Client will elect a contractor to undertake the dynamic compaction works at the Site. As such, it is recommended that additional information, including the type of equipment, expected peak particle velocity (PPV), expected frequency and method of works be provided to GHD once confirmed. Additional information on the influence of the above inputs is explained in section 3.2.

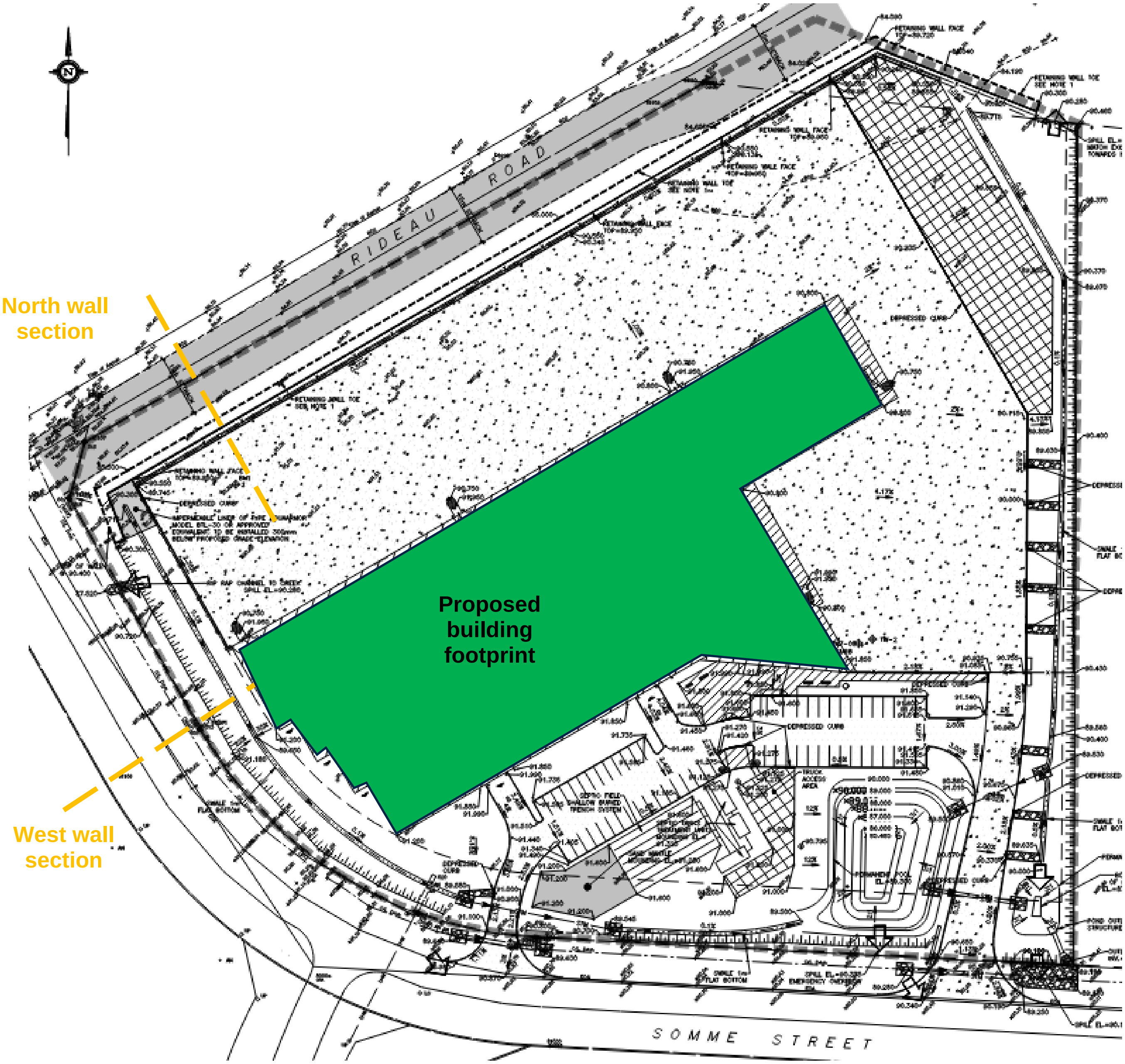

Figure 1.1 Site layout showing the location of the analysed cross sections and the proposed building footprint

2. Review of pre-construction geotechnical information

GHD has reviewed the following geotechnical investigations while preparing this letter:

– Geotechnical Study Subdivision Plan, Hawthorne Industrial Park, report ref. no. T020556-A1, by Inspec-Sol, dated May 4, 2009.

– Geotechnical Investigation, Warehouse and Offices Intersection of Rideau Street, report ref. no. 11215612-A1, by GHD, dated September 10, 2020.

GHD is currently conducting a supplementary geotechnical investigation at the Site. The results of this investigation are not available yet for use in this study. The results may, therefore, change based on the results of the ongoing geotechnical investigation at the Site.

GHD has also reviewed the following documents provided by the client as part of the assessment:

– Grade Control and Drainage Plan, Somme St, Ontario, Fastfrate facility, Job No. A001083-C006, by CIMA+, dated March 8, 2021.
– Draft Floor Plan, New Warehouse & Cross-Dock Facility, Fastfrate Ottawa, Somme Street, Ottawa, Ontario, Job No. 2001-A1, by CIVITAS, dated April 28, 2021.
– West slope cross-section, 2001-FastFrat-Civil Section-July 21, 2021_comm_GHD, by CIVITAS, received July 26, 2021.
– North slope cross-section, C006B_Grading, by CIMA+, received July 28, 2021.

3. Slope stability assessment

3.1 Subsurface conditions

As per the documentation reviewed and listed in Section 2, in general, soils encountered at the borehole locations consisted of a thick layer of fill material overlying native silty sand to sandy silt deposit followed by a glacial till. Limestone bedrock with interbedded sandstone was encountered at depths ranging from 8.2 (BH1) to 11.9 mbgs (BH3).

General descriptions of the subsurface conditions are summarized as follow:

1. Fill - consisting of a mixture of sand, silt, clay, and gravel. The fill material contains traces to some asphalt, concrete, wood and brick fragments, topsoil, and pieces of reinforcing steel. The composition of fill varied with depth and borehole location. Cobbles and possible boulders were encountered in the boreholes at varying depths. The thickness of the fill at the borehole locations was approximately six (6) metres.
2. Native sandy silt - below the fill material a native deposit of sandy silt to silty sand with varying amounts of clay and gravel was encountered. Cobbles and possible boulders are expected within this deposit becoming more frequent with depth. The deposit extended to depths ranging from 8.2 to 11.9 mbgs.
3. Bedrock - limestone bedrock with interbedded sandstone was encountered below the native sandy silt.
4. Groundwater - groundwater levels were measured on August 18, 2020, groundwater elevation of 87 metres was encountered at the monitoring wells.

The selected geotechnical parameters for the Site soils used in the analysis are summarized in Table 3.1.

Table 3.1 Geotechnical parameters

Material	Unit weight (kN.m^3)	Cohesion (kPa)	Internal friction angle (°)
Existing fill	19	2	28
Native sandy silt	20	2	34
Bedrock	N/A (considered impenetrable)		

3.2 Vibration analyses

Dynamic compaction is comprised of repeatedly dropping a 5 to 40 tons mass freely from a heigh of 10 to 40 metres on a grid pattern. Dynamic compaction can densify suitable materials up to ten (10) metres thick. Suitable materials are saturated free-draining soils, low moisture content poorly draining soils (moisture content lower than plastic limit) and silts with a plasticity index of less than eight (8). Due to the dropping of the heavy mass vibration is generated from the dynamic compaction works to the surrounding soil. Vibration then propagates through the surrounding soil until the vibration wave attenuates completely. If the vibrations exceed certain threshold limits for level or sloping ground conditions, ground displacements may occur. In addition, vibrations can cause a reduction in the shear strength of soils. As such, construction vibrations such as dynamic compaction need to be taken into account in the stability analyses.

Vibrations are a function of the amount of energy that gets dissipated with increase in distance from the source of energy. The established energy versus distance relationship is exponential in nature, meaning that an exponential reduction in vibration is realized with increasing distances. The energy measured as a function of Peak Particle Velocity (PPV) although meeting the specified criterion at the specified locations was exponentially higher when travelling through the slope at shorter distances from the source of vibration.

As indicated earlier, vibration (measured as PPV) energy gets dissipated with time as soil conditions have a damping effect on vibration. PPV follows a reverse log curve on an exponential scale, therefore, values begin very high near the source of vibrations and drop off rapidly farther from the source. A slope can experience movements if ground acceleration ‘a’ due to gravity exceeds yield acceleration (Ky) values[1].

Ground acceleration 'a' is related to PPV through the frequency of motion 'F', assuming sinusoidal motion, using the following equation:

$$a = 2 * \pi * PPV * F \qquad \text{Eq. (1)}$$

Where:

– PPV = Peak Particle Velocity in mm/sec

– F = Frequency in Hz

For the west wall with a platform extended four (4) metres from the building footprint, the PPV was estimated to be 0.5 inches per second as shown in Figure 3.1 for a two-ton drop ball with a 40-foot drop.

1 Matasovic' N., (1991): Selection of Method for Seismic Slope Stability Analysis. Proceedings: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, 1991, St. Louis, Missouri, Paper No. 7.20

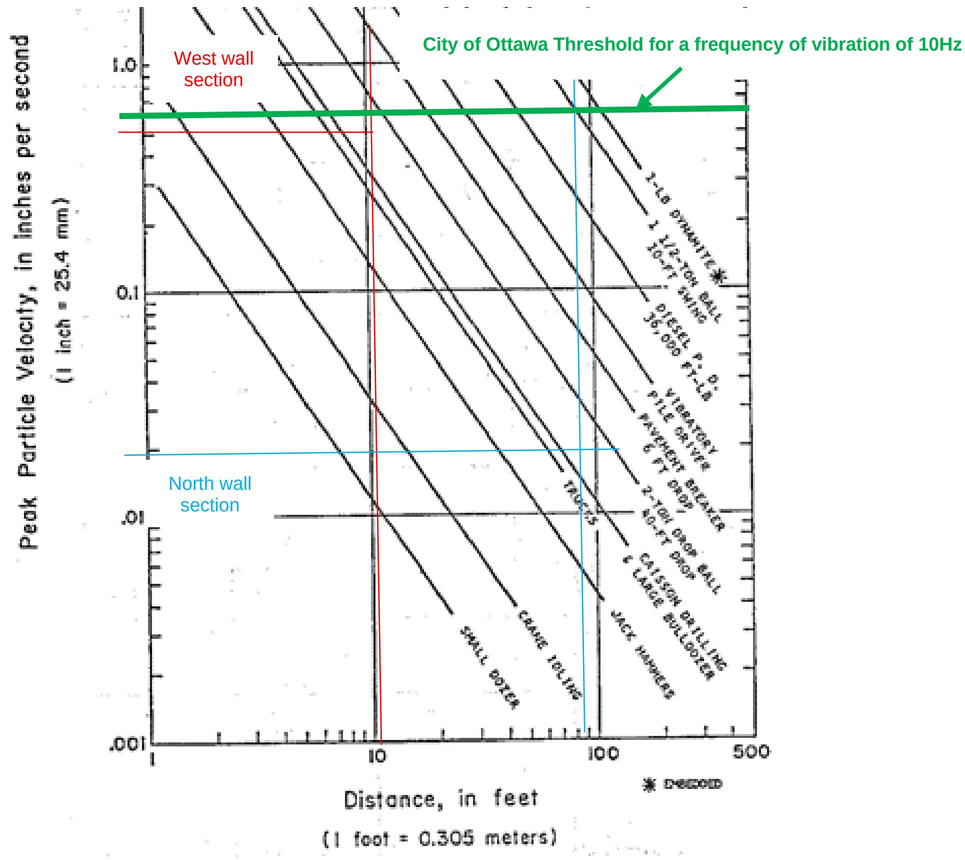

Figure 3.1 Dynamic compaction PPV estimation for west wall

Due to the lack of information available at this stage of the design, it was also assumed that a maximum frequency of motion for the machinery of 10 Hz for construction operations[2].

As such the ground acceleration for the slope stability analysis for the west wall is estimated to be:

$$a = 2*3.14159*0.5*10 = 31.4 \text{ in/sec}$$

$$a = 0.08 \text{ g}$$

For the north wall with the slope crest located 35 metres from the building footprint, the PPV was estimated to be 0.02 in/sec as shown in Figure 3.1 for a 2 Ton drop ball with a 40-foot drop. As such the ground acceleration for the slope stability analysis for the west wall is estimated to be:

$$a = 2*3.14159*0.02*10 = 1.26 \text{ in/sec}^2$$

$$a = 0.003 \text{ g}$$

2 OSM Blasting Performance Standards 30 Code of Federal Regulations

However, the graph is based on a two-ton drop ball, the dynamic compaction methodology is not available at this stage of the design and will be the responsibility of the ground improvement contractor. As such, the dynamic compaction may involve drop mass ranging from 5 to 40 tons, therefore, the following conservative acceleration values were used for the preliminary analyses:

West wall: a = 4 x 0.08 g = 0.32 g

North wall a = 4 x 0.003 g = 0.12 g

The above values should be reviewed by the ground improvement contractor and if required, GHD should be requested to revise the slope stability analyses.

3.2.1 Vibration limits

The vibrations limits within habited areas are set to avoid disturbance to inhabitants and to avoid damage to the structures. The criteria in Table 3.2 are, typically, set for a construction site.

Table 3.2 Prohibited construction vibrations

Frequency of vibration (Hz)	Vibration PPV (mm/sec)
Less than 4	8
4 to 10	15
More than 10	25

3.3 Western wall

A slope stability assessment was performed for the existing slope along the west perimeter of the Site. GHD's understanding of the existing slope conditions is based on the cross-sections provided by CIVITAS. Analysis was performed on the existing slope under static condition and pseudo-static (i.e., construction vibrations) conditions using effective soil parameters.

The slope stability analysis was carried out using the SLOPE/W 2019 software package produced by GEO-SLOPE International Ltd. Each trial was modelled using the Morgenstern-Price method, and the optimized critical slip surface was selected. In general, this approach calculates a factor of safety that represents the ratio of forces resisting a failure (i.e., shear strength, friction, etc.) to those favouring failure (weight, external loading, etc.). Theoretically, a factor of safety of 1.0 would represent an equilibrium condition (i.e., a marginally stable slope). However, the City of Ottawa recommends a minimum factor of safety of 1.5 under static conditions and 1.1 under pseudo-static conditions to account for uncertainty in soil parameters used and slope geometry.

Due to the lack of information at this stage of the design, a distributed load of 250 kPa approximately three meters away from the building edge was assumed to represent the crane used during dynamic compaction. The 250 kPa was determined based on GHD’s experience and assumed to be spread over two tracks of three meters in length. The three meters offset was assumed to model a conservative reach of the machinery and is assumed based on GHD’s experience. Additionally, it was assumed that a swale at the base of the slope will be constructed to direct the runoff away from the pad.

A summary of the analyses is shown in Table 3.3, with the graphical output for the analysis for each condition provided in Appendix A.

Table 3.3 Slope stability results

	Factor of safety
Static	1.6
Pseudo static	1.1

Based on the preliminary slope stability analysis, depending on the composition and compactness state of the fill material, the factor of safety for the slope is above or equal to (i.e., 1.6 under static condition and 1.1 under pseudo-static condition) the recommend values of 1.5 for static condition and 1.1 for pseudo-static condition. Some sloughing and bulging-type movements at the west slope could be expected during the dynamic compaction. The slope will need to be restored to its design grades under-engineered controls after dynamic compaction is complete and before the proposed building is constructed.

The ground improvement contractor must review the vibration assumptions made during the above analyses and provide his input.

3.4 Northern wall

A slope stability assessment was performed for the existing slope along the north perimeter of the Site. GHD's understanding of the existing slope conditions is based on the cross-section provided by CIMA+. Analysis was performed on the existing slope under static conditions and pseudo-static (i.e., seismic) conditions considering drained soil conditions.

The slope stability analysis was carried out using the SLOPE/W 2019 software package produced by GEO-SLOPE International Ltd. Each trial was modelled using the Morgenstern-Price method, and the optimized critical slip surface was selected. In general, this approach calculates a factor of safety that represents the ratio of forces resisting a failure (i.e., shear strength, friction, etc.) to those favouring failure (weight, external loading, etc.). Theoretically, a factor of safety of 1.0 would represent a stable slope. However, the City of Ottawa recommends a minimum factor of safety of 1.5 under static conditions and 1.1 under pseudo-static conditions. The selected geotechnical parameters for the Site soils used in the analysis are summarized in Table 3.1.

A summary of the analyses is shown in Table 3.4, with the analysis for each condition provided in Appendix B.

Table 3.4 Slope stability results

	Factor of safety
Static	2.1
Pseudo static	1.4

Based on the preliminary slope stability analysis, depending on the composition and compactness state of the fill material, the factor of safety for the slope is above (i.e., 2.1 under static condition and 1.4 under pseudo-static condition) the recommend values of 1.5 for static condition and 1.1 for pseudo-static condition. It is noted that in this case the dynamic compaction works being 35 metres from the slope’s crest has a negligible impact on the slope stability. Additionally, the condition of the slope must be monitored during site preparation and building construction.

4. North wall retaining wall

GHD understands that due to the required facility footprint, a retaining wall will be constructed along the Site's north boundary due to vehicle circulation constraints and to redirect the storm water drainage to the south. It is also understood that the retaining wall design will be completed by others and the wall will be sitting on the native material, which will require the excavation of the existing fill. At this stage of the design, the intent is to use a gabion-type wall using the fill available on Site from the Site excavations. It is GHD's opinion that the on-site material can be reused to raise the pad before dynamic compaction work or for the retaining wall construction as long as it is comprised of mineral soils only. Note that some organic materials have been noted within the fill. Also, buried asphalt was observed in some boreholes during the field investigation. Please note that this recommendation does not take into account environmental considerations if any.

Literature-based parameters for the existing fill are provided in **Erreur ! Source du renvoi introuvable.** for the design of the mechanically reinforced earth (MSE) retaining wall, which will be designed and constructed by others using the existing fill material available on-Site.

Table 4.1 North slope retaining wall parameters

Parameter	Value
Cv - coefficient of consolidation (m^2/year)	1 to 10 m^2/year
K - permeability (cm/sec)	10^{-4} to 10^{-7} cm/sec
Mv - coefficient of volume compressibility (m^2/MN)	0.05 to 0.2 /MPa
Cc - compressibility index	- 0.2
Unit weight (kN/m^3)	19
Friction angle (degrees)	28 - 34
Cohesion (kPa)	0 - 2

The other following recommendations are provided:

– It is recommended that compaction of the fill be completed using layers with a thickness of 200 millimetres (mm) to achieve a 95 percent proctor.

– For the capping prior to dynamic compaction, an initial 300 mm can be OPSS Granular 'B' Type 1 material. The final surface 300 mm capping material must be either OPSS Granular 'A' or well-graded 19 mm or 50 mm crusher run limestone meeting Granular A or Granular B gradation requirements, compacted to 100 percent standard Proctor maximum dry density.

5. Vibration monitoring and contingency plans

GHD understands that dynamic compaction will be undertaken on the building footprint only as shown on Figure 1.1. Additionally, as mentioned in Section 3.2, the dynamic compaction methodology is not known at this stage of the design and remains the responsibility of the ground improvement contractor. Nevertheless, during the dynamic compaction vibration works, monitoring must be carried out using approved seismographs/accelerometers. Continuous readings must be recorded for one week prior to the start of construction. Continuous readings comprised of PPV and construction frequency in all directions then must be recorded throughout construction at Site boundaries and any nearby structures. Readings must be checked at least once per day to ensure that the vibration levels are not exceeding the specified limits.

Should the recorded vibrations exceed the allowable limits recommended in Section 3.2.2 above, the ground improvement contractor together with GHD should review and modify the ground improvement methodology. The modifications may include reductions in the drop weight, drop height, or both, while increasing the number of drops per impact point. These assumptions are based on the empirical formula used to estimate the depth of improvement using the dynamic compaction method as given below:

$$D_i = n_c \, (W_t \, H_d)^{0.5}$$

Where:

Di = Depth of improvement

n_c = Constant, depending on soil type, degree of saturation, and speed of drop [nc values range from [0.35 (clays) to 0.5 (gravelly soils)]

W_t = Weight of hammer (tons)

H_d = Height of drop (m)

The fill soils at the Site extend to a depth of 6 m. For the silty clayey soils, a n_c value of 0.4 can be used for a preliminary design, resulting in a W_tH_d = 225. Assuming a drop of 15 m, a 15 ton weight will be required to be dropped to compact the soils to a depth of 6 m. As already discussed, vibrations reduce exponentially as distance form the source of vibrations increases until these are within tolerable limits before damping out completely. Before commencing the dynamic compaction operations, theoretical distance at which the vibration will reduce to allowable limits (Safe Distance) will be calculated using the parameters provided by the ground improvement contractor. It will be ensured that no sensitive structure is located within the Safe Distance. Alternatively, the dynamic parameters would be revised, and the Safe Distance recalculated. The theoretical Safe Distance will be confirmed through actual measurements and the dynamic compaction procedure modified if the vibrations are found to exceed the allowable limits at Safe Distances/boundaries.

6. Conclusion

- The west and north slope are stable under static and pseudo-static conditions under the described assumptions.
- The west slope could experience some minor instability during dynamic compaction, which will require restoration works post dynamic compaction.
- It is recommended that the pad be extended with a minimum distance of four (4) metres and a 3H:1V slope before the start of the dynamic compaction works. It should be noted that this distance should be updated once the dynamic compaction construction method has been detailed (i.e., compaction weight and height, equipment, expected frequency).
- The north and west slope should remain stable during the dynamic compaction process using the described assumptions.

- GHD has carried out the analysis using assumed dynamic parameters and before the completion of the supplementary geotechnical investigation taking place at the Site. The ground improvement contractor should review the dynamic compaction parameters assumed in this study. GHD should revise the study based on the comments from the ground improvement contractor and the results of the ongoing geotechnical investigation.
- Before commencing the dynamic compaction operations, theoretical distance at which the vibration will reduce to allowable limits (Safe Distance) should be calculated using the parameters provided by the ground improvement contractor. It will be ensured that no sensitive structure is located within the Safe Distance.

Regards,

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Copy to: David Rizk, GHD

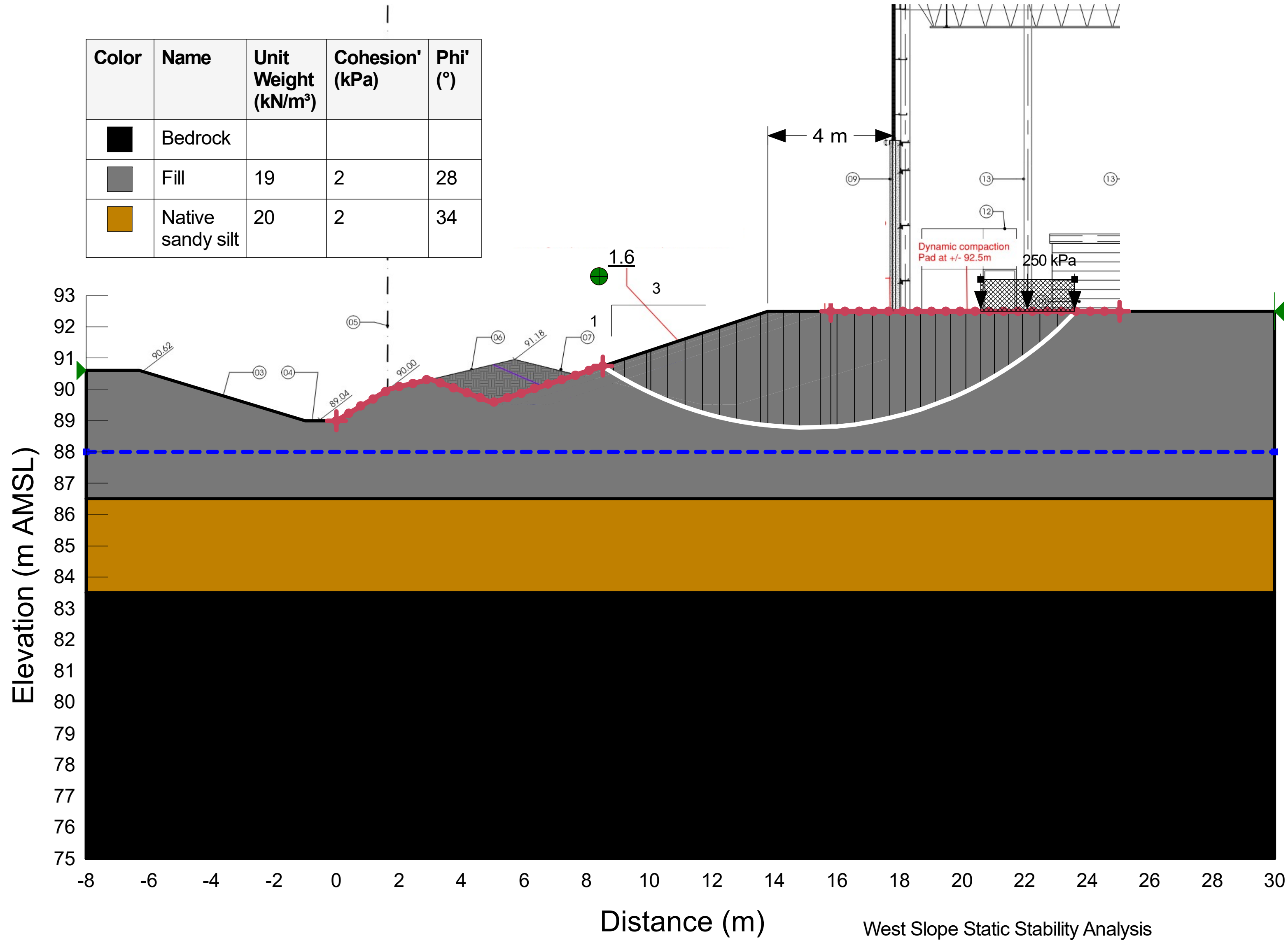
Encl.

Appendices

Appendix A

West slope analysis results

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock			
	Fill	19	2	28
	Native sandy silt	20	2	34



West Slope Static Stability Analysis
Ground Improvement Using Dynamic Compaction
Proposed Warehouse and Offices
Rideau Road and Somme Street, Ottawa, Ontario
11228236

04/08/2021

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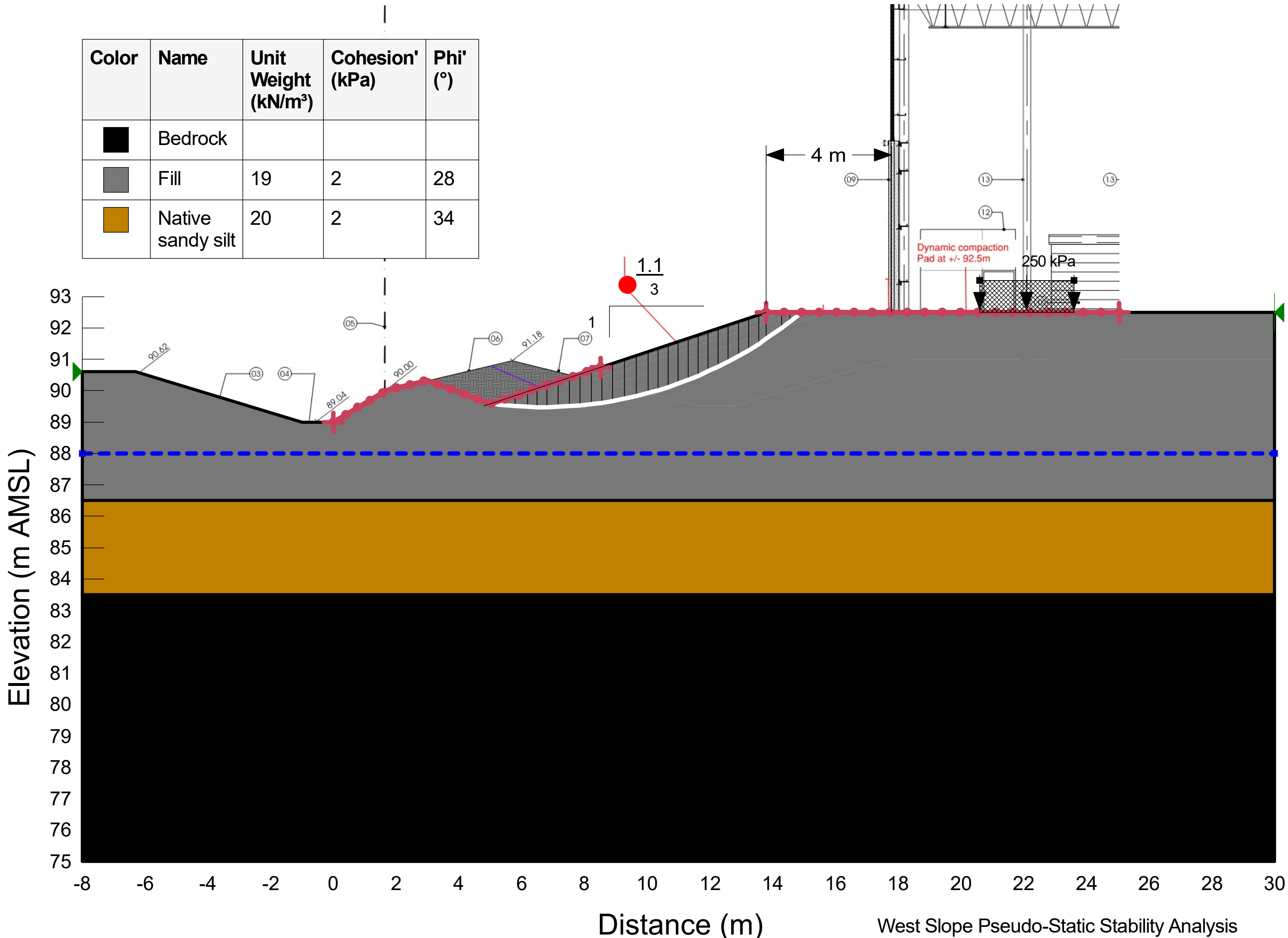
Seismic Coefficient = 0.32



Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock			
	Fill	19	2	28
	Native sandy silt	20	2	34

West Slope Pseudo-Static Stability Analysis
Ground Improvement Using Dynamic Compaction
Proposed Warehouse and Offices
Rideau Road and Somme Street, Ottawa, Ontario
11228236

04/08/2021

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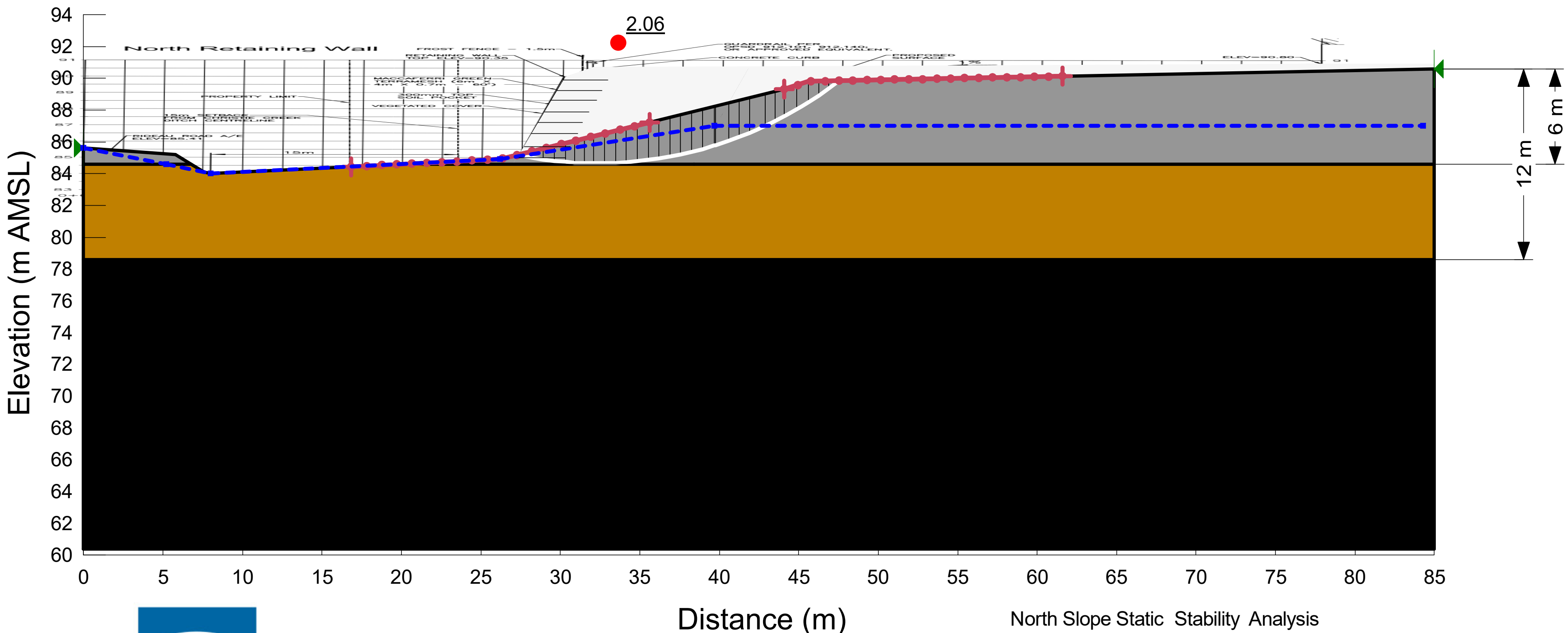
Appendix B

North slope analysis results

Color	Name	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)
Black	Bedrock			
Grey	Fill	19	2	28
Orange-brown	Native sandy silt	20	2	34



North Slope Static Stability Analysis
Ground Improvement Using Dynamic Compaction
Proposed Warehouse and Offices
Rideau Road and Somme Street, Ottawa, Ontario
11228236

03/08/2021

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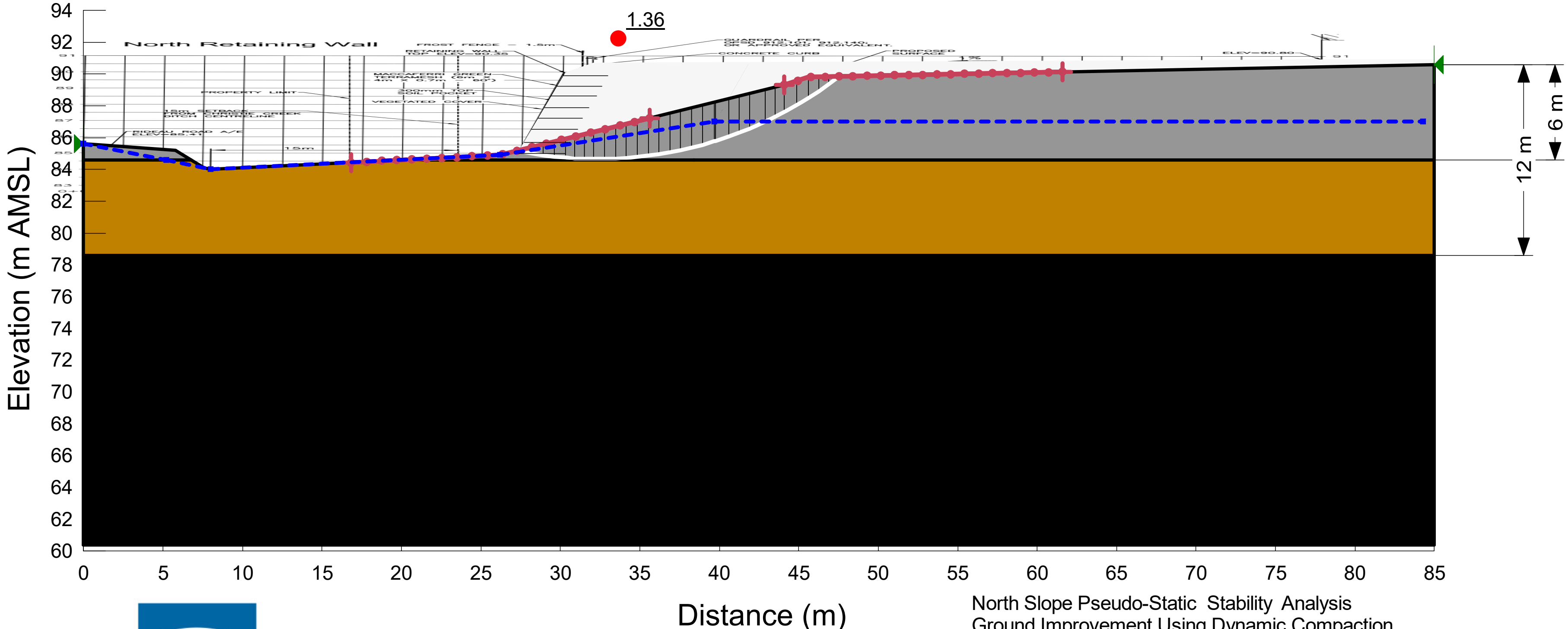
Color	Name	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Bedrock			
	Fill	19	2	28
	Native sandy silt	20	2	34

Seismic Coefficient = 0.12



North Slope Pseudo-Static Stability Analysis
Ground Improvement Using Dynamic Compaction
Proposed Warehouse and Offices
Rideau Road and Somme Street, Ottawa, Ontario
11228236

03/08/2021

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