November 28, 2017

DRAFT FOUNDATION INVESTIGATION AND DESIGN REPORT

Rock Slope Inspection - Segment 11 Highway 33 from Adolphustown to Collins Bay (Kingston) Agreement No. 4014-E-0012 Assignment No. 14

Submitted to:
Ministry of Transportation, Ontario
Engineering Office
1355 John Counter Blvd.
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DRAFT REPORT

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AGREEMENT NO. 4014-E-0012 – ASSIGNMENT NO. 14

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by the Ministry of Transportation, Ontario (MTO) under the Eastern Region Foundation Engineering Retainer (Agreement No. 4014-E-0012) to carry out a geotechnical inspection and stability assessment of three rock slope sites located in close proximity to Highway 33 and provide recommendations for remedial options for each site. This report addresses Segment 11 which is the last of three slopes identified by MTO under this assignment.

2.0 BACKGROUND

On behalf of MTO, Coldwater Consulting Ltd. (Coldwater) carried out a shore hazard analysis along Highway 33 between Adolphustown and Collins Bay (Kingston), Ontario. The results of this investigation are summarized in Coldwater's report Shore Hazard Analysis, Hwy 33 Kingston to Adolphustown, dated June 20, 2016. Coldwater analyzed a total of 47 shoreline segments for geomorphology, geometry, wave exposure, erosion hazard and slope stability, considering timeframes of 100 years, 30 years, and present day. Of the eight shore segments identified as needing new shore protection under present day conditions, Coldwater noted that three of these eight segments (Segments 3.10, 7, and 11) are considered critical since they have undercut rock slopes in close proximity to Highway 33.

Golder was subsequently retained by MTO to inspect and assess the three shore segments identified by Coldwater as critical in order to provide options for slope remediation for each site.

The Terms of Reference and Scope of Work are outlined in MTO's Work Item Order Form No. 14 of Agreement No. 4014-E-0012 dated November 3, 2016. The detailed scope of work is presented in Golder's Understanding of Scope document. Authorization to proceed was received from MTO via the executed Work Item Quote Form No. 14 on November 17, 2016.

3.0 SITE LOCATION AND DESCRIPTION

The three critical segments of concern, as identified by Coldwater are located along the shoreline of Lake Ontario next to Highway 33, west of Kingston, Ontario. The slope locations are summarized in Table 1.

Table 1: Location of Investigated Sites

Critical Segment ID	Start Chainage (Hwy 33)	End Chainage (Hwy 33)	Length (m)	Description
Segment 3.10	20+300	20+433	133	Approximately 1 km west of intersection with County Road 21
Segment 7	12+050	12+260	210	Approximately 1 km east of Lafarge's Bath Cement Plant
Segment 11	18+333	18+428	95	Approximately 600 m east of intersection with County Road 4

Rock slope Segment 11 comprises a 95 m long limestone rock face that is located along the shoreline of Lake Ontario, close to Highway 33 between Adolphustown and Collins Bay (Kingston), Ontario. The site is located approximately 600 m east of the intersection of Highway 33 and County Road 4. Figure 1 shows the location of the site with respect to the shoreline along Highway 33.

4.0 INVESTIGATION PROCEDURES

The site investigation was carried out in two parts. The first part, which was carried out by Golder on December 1-2, 2016, involved a visual inspection of the three segments from the top of the slopes and from a boat which was used to approach the slopes from Lake Ontario.

The second part of the site investigation involved an air-borne LiDAR survey of the three rock slope segments using a helicopter. Due to the windy and snowy weather conditions at the investigation site during early December and the snow cover on the rock slope segments, the LiDAR survey had to be deferred until the snow had melted. The LiDAR survey was carried out on January 20, 2017 by Rocky Mountain Equipment Geomatics. A second LiDAR survey was also carried out from a boat on the lake in order to collect additional data for the steep rock faces and overhangs which were not visible from the helicopter survey locations.

A study was also conducted using satellite imagery taken over a number years to determine if any erosion rates or shoreline changes could be observed. Imagery was compiled and compared from 1948, 1962, 1986, 2010 and 2014 surveys along Segment 11.

5.0 SITE OBSERVATIONS

Highway 33 is a two-lane highway with an approximately 1.3 m wide paved shoulder on either side of the road and a guardrail along the south side of the road bordering Lake Ontario. Figure 2 contains various photographs of the site investigation which highlight critical features of the rock face as well as showing a full panorama of the overall rock slope.

5.1 Segment 11

5.1.1 Site Description

Rock slope Segment 11 is approximately 98 m long as measured along the guardrail of Highway 33. The crest of the rock slope is approximately 1.5 m below the road grade of Highway 33. This segment has the highest slope height of the three critical segments that were identified in the Coldwater (2016) report. Figure 3 provides examples of the appearance of the tall steep rock faces or cliffs which vary in slope angle.

5.1.2 Rock Slope Conditions

The rock mass consists of a slightly weathered, very thinly to thinly bedded, grey limestone interbedded with fissile shale (refer to Figure 4). The bedding is approximately horizontal and the rock mass is very blocky and fractured which contributes to the rate of erosion of the rock slope. Some of the developing erosion areas and open fractures at surface would indicate that there is likely a sub-vertical joint set oriented approximately east-west or about 080º and a second sub-vertical joint set oriented approximately north-south.

The shoreline of Segment 11 is approximately parallel to Highway 33. The crest line of the rock slope is irregular in shape due to the erosional features that have been carved out of the rock cliff through wave action. Rock columns have begun to form in certain areas due to sections of the slope that have failed or eroded over time. There is a depression visible in the grass near the east end of the slope segment which is approximately parallel to Highway 33. This depression is assumed to be an indication of a large open discontinuity in the bedrock below.

Due to rough water conditions while inspecting from the boat on Lake Ontario, it was not safe to approach the rock slope for detailed measurements. As a result, the vertical height of the rock slope could not be measured, however it is comparatively much taller than both Segment 3.10 and Segment 7. Figure 4 provides a closer look at the rock cliffs showing examples of the weathering and resulting blockiness of the limestone rock mass.

A hydro pole is located near the crest of the rock slope approximately 17 m from the west endpoint. Both the hydro pole and guy wire anchor are founded in what appears to be fractured rock approximately 6 m and 1 m from the crest respectively. Figure 5 shows the location of the pole along Segment 11.

Open Discontinuities on Surface

Vertical cracks are developing on the rock faces oriented perpendicular to Highway 33. There is some undermining present at the water level, although the extent of this undermining could not be measured due to the rough water conditions during the boat inspection.

There are also two potential open discontinuities developing near the west end of Segment 11 located about 13 m and 23 m from the west endpoint. Both of these discontinuities appear to be developing with a strike of approximately 70º, which is consistent with the orientation of the adjacent rock face.

Near the east end of Segment 11, the depression in the grass could also be an open discontinuity. Figure 6 shows multiple examples of these vertical discontinuities close to the guardrail and crests of the slopes.

Vegetation

Vegetation does not appear to be a significant influence to the rock slope stability at Segment 11, however, there are numerous trees which have rooted themselves into the rock slope. These roots could have an effect over time as they continue to grow. Figure 7 shows various locations where tree roots have been growing into the rock slope faces which could, in time result in a widening of the fractures.

Distance to Highway 33

The crest of slope Segment 11 is roughly parallel to Highway 33. The crest ranges from about 2.4 m to 17 m from the guardrail of Highway 33. The depression in the grass that runs sub-parallel to Highway 33 near the east end of the slope is located approximately 7 m to 7.5 m from the guardrail. Figure 8 provides images of the large variation in proximity of the slope crest to the guardrail whereas Figure 9 shows how close some of the open discontinuities are with respect to the guardrail of Highway 33.

5.1.3 Water Level and Wave Action

There is no beach or rock shelf visible at the toe of the rock slope. The water level is part-way up the rock slope and, as a result, wave action impacts directly on the rock face, eroding and undercutting the slope.

According to the Coldwater report (2016), the wave heights for Segment 11 range from approximately 0.86 m up to 1.3 m, with an average of 1.1 m. This range is much lower than Segment 3.10, and similar to Segment 7, likely because Amherst Island provides shelter from the open water wave action of Lake Ontario.

Plate 1 shows how the wave height is measured to obtain an average of approximately 1.1 m for Segment 11.

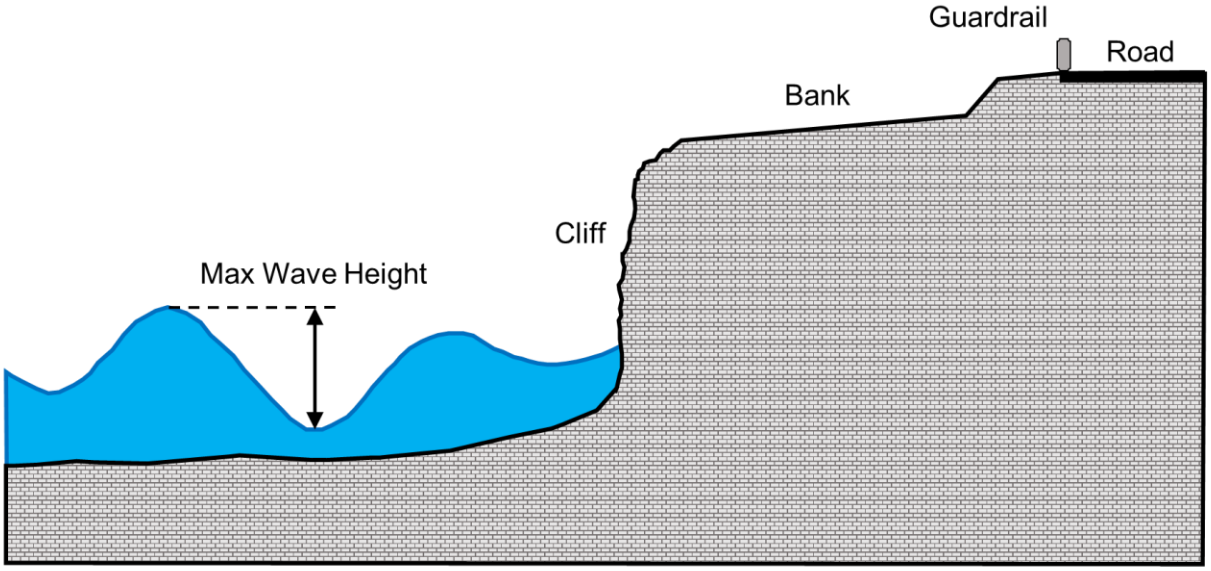

Plate 1: Schematic of Maximum Wave Height (modified from the 2016 Coldwater report)

5.1.4 Erosion Rates

Erosion along the shoreline has several important implications for slope stability and therefore for this study. Due to the location of Segment 11, this rock slope has a tendency to be undercut resulting in large overhangs and cave-like features with open vertical joints. If these overhangs and cave-like features collapse, this could result in a significant loss of ground rather than a slow gradual slope erosion. Environment Canada – Ontario MNR (1975) presented erosion data from 0 m up to 0.12 m/year from 1936-1967; however, there are no details on the exact location or shore type (i.e. rock, soil etc.). Monitoring of erosion rates at critical locations would provide some useful insight which would assist in the determination of urgency of any remedial work. Figure 10 shows examples of significant undercutting due to erosion along the segment while Figure 11 shows cave and pillar-like structures being created by the erosion processes along Segment 11.

In order to try to assess the long-term erosion rates, an aerial photograph interpretation study was carried out to compare the shoreline location at different points in time. Available photographs from 1948, 1962 and 1986 were of too low quality resolution for an accurate assessment of the shoreline. However, both 2010 and 2014 satellite imagery provided high enough quality images that localized erosion of the shoreline was visible as notches; Figure 12 shows the comparison of the shoreline between these two years. The original shape of the small notches are more rounded and shallow in 2010, however by 2014 these notches not only became more jagged, but increased in depth towards the highway. Since these notches are close to each other, the overall shoreline will likely regress in the deepened shape of these notches. Unfortunately, image quality was insufficient for obtaining a measurable change in the distance between the shoreline and the highway.

5.1.5 LiDAR Survey Results

Results of the LiDAR survey carried out from a helicopter and from a boat are presented in Figures 13 to 17. From the LiDAR point cloud data, five cross-sections, labelled as C1 to C1’ through to C5 to C5’, were produced to illustrate typical rock slope profiles along the segment.

Section C1 to C1'

Cross-section C1 to C1' is displayed on Figure 13. The LiDAR data for this location shows a 4 m vertical cliff face approximately 4 m from the shoulder of the road. The ground surface declines at a slope of approximately 3.5H:1V from the road to the edge of the cliff. The cliff face has been undercut to a depth of up to 1m due to the wave action described in Section 5.1.3. This is the greatest depth of an erosional feature in the five cross-sections examined in Segment 11. This is also the location of one of the potential open discontinuities that appear to be developing at a strike of approximately 70º.

Section C2 to C2'

Cross-section C2 to C2' is displayed in Figure 14. The distance between the road and cliff is only approximately 2.5 m in this location, and the cliff face drops 5.5 m to the water. This section has the tallest cliff face and least distance between cliff and road of any of the five cross-sections examined along Segment 11. Erosional features up to 0.75 m deep are visible on the cliff face.

Section C3 to C3'

Cross-section C3 to C3' is displayed in Figure 15. The edge of the cliff in this location is approximately 4.75 m from the road, and the cliff face drops 4.25 m into the water. Characteristic erosional features up to 0.75 m deep can again be seen on the cliff face.

Section C4 to C4'

Cross-section C4 to C4' is displayed in Figure 16. The crest of the slope is approximately 3.75 m long at this location, and increases in slope until transitioning into a 3.5 m vertical cliff face. The rock face has been eroded to a depth of up to 0.5 m.

Section C5 to C5'

Cross-section C5 to C5' is displayed in Figure 17. Erosional features typical of Segment 11 can again be seen in the cliff face at this location where wave action has undercut the rock by up to 0.5 m. The cliff face is approximately 4 m high, and 8 m from the road. The apparent gap in data near the center of the cross section shows the location of the depression in the ground surface described in section 5.1.2.

5.1.6 Summary

A summary of the site conditions from observations taken by Coldwater in 2015 and from Golder's 2016 investigation is provided in Table 2. Table 2 provides site specific observation data as well as measured data such as wave heights and elevations of the cliff geometries.

Table 2: Summary of Segment 11

Length	Exposure	Shoreline type	CRCA Classification	Average Toe Elevation	Average Cliff Height	Average Wave Height	Description
(m)				(masl)	(m)	(m)	
98	Confined Channel=6	Erosive Bedrock,	High Bedrock	74.99	5.85	1.12	Undercut Cliffs, no talus beach. Many

Length	Exposure	Shoreline type	CRCA Classification	Average Toe Elevation	Average Cliff Height	Average Wave Height	Description
(m)				(masl)	(m)	(m)	
		Till overburden					vertical joints, heavily weathered.

CRCA – Cataraqui Region Conservation Authority

Based on Golder's observation of the site, the presence of undercut cliffs confirms that the rock is erodible. The very blocky, weathered and fractured rock mass contributes to the erosion rate of the cliff face at water level. Vegetation was seen rooting directly into the bedrock; however their presence and the layer of overburden do not appear to have an adverse effect on the condition of the cliffs. The near-vertical cliff faces also indicate a 'High Bedrock' condition according to the CRCA classification, indicating that the bedrock is currently strong enough to support itself without collapsing into a slope; however it is still weak enough to collapse and fail in small localized areas due to the ongoing development of overhanging rock and open discontinuities forming rock columns.

6.0 CLOSURE

This Foundation Investigation Report was prepared by Sarah Pidgen, P.Eng., and reviewed by Mark Telesnicki, P.Eng., a senior rock mechanics engineer and RAQS Rock Hazard Specialist at Golder. Lisa Coyne, P.Eng., a Designated MTO Foundations Contact for Golder, conducted an independent quality review of the report.

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PART B

FOUNDATION DESIGN REPORT
HIGHWAY 33 – ROCK SLOPE INSPECTION, SEGMENT 11
ADOLPHUSTOWN TO COLLINS BAY (KINGSTON), ONTARIO

AGREEMENT NO. 4014-E-0012 – ASSIGNMENT NO. 14

7.0 GEOTECHNICAL ENGINEERING ASSESSMENT AND ANALYSIS

7.1 General

Golder has been retained by the Ministry of Transportation (MTO), Ontario under MTO's Eastern Region Foundation Engineering Retainer (Agreement No. 4014-E-0012) to carry out a geotechnical stability assessment of three rock slope sites located along Lake Ontario just west of Kingston, Ontario, parallel to Highway 33 and in close proximity to the roadway. The three segments (Segment 3.10, Segment 7, and Segment 11) were previously identified by Coldwater Consulting Ltd. during their Shore Hazard Analysis and were listed as "critical segments requiring immediate attention" in their report dated 20 June 2016.

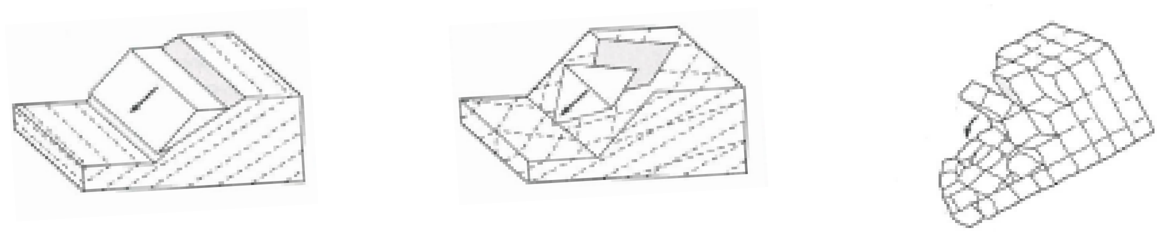
The following sections of this report provide a summary of the geotechnical engineering assessment and remedial recommendations for Segment 11 along Highway 33. The recommendations are based on interpretation of the data obtained from the visual site inspection and aerial photograph interpretation carried out by Golder as well as the LiDAR surveys conducted by Rocky Mountain Equipment Geomatics. The discussion and recommendations contained in this Foundation Design Report (Part B) are intended for the use of the MTO and its designer, and shall not be used or relied upon for any other purpose or by any other parties, including the construction or design-build contractor (if applicable). The contractor must make their own interpretation based on the factual data in the Foundation Investigation Report (Part A). Those requiring information on the aspects of construction must make their own interpretation of the factual information provided as such interpretation may affect equipment selection, proposed construction methods, scheduling and the like.

7.2 Potential Failure Mechanisms

Rock mass structure refers to the nature and occurrence of discontinuities within a rock mass. Discontinuities refer to all fractures occurring within the rock mass, including joints, bedding planes and faults. These discontinuities represent weakness planes, which can reduce the effective rock mass strength as they increase in size (persistence) and decrease in spacing (increase in frequency). The spacing, orientation and continuity (persistence) of discontinuities govern the size and shape of blocks within the rock mass. Wall roughness, aperture, size, infilling materials, and water conditions define the nature of the discontinuities and control the shear resistance along the discontinuity. Structurally-controlled rock failures occur as a result of movement along these discontinuities (joints/fractures and bedding planes). The presence of a discontinuity itself does not result in failure, but rather provides a plane of weakness which may contribute to failures in the rock face, such as the intersecting vertical joints observed along the segment.

The three basic mechanisms of structurally-controlled failure in rock slopes are planar failures, wedge failures and toppling failures (refer to Plate 2).

Planar failure describes the sliding of rock blocks on inclined discontinuities in the rock mass. Planar failures will generally only develop to a significant extent if the strike of the geologic discontinuity is within ±20° of the strike of the rock slope. Wedge failure describes the sliding of a rock block along two intersecting discontinuities. Wedge failures will only develop to a significant extent if the azimuth of the line of intersection is within ±45° of the dip direction of the slope face. Both of these mechanisms were not observed at this site as the blocky rock mass contained only very steep to vertical cross-joints and relatively flat bedding. Toppling describes the rotational fall of rock blocks from a steep or vertical rock surface. Toppling failure may develop when continuous joints/discontinuities strike nearly parallel to the strike of the face of the rock slope and the weight of the rocks above is not supported by the blocks below. Toppling failure is possible at Segment 11 due to the numerous vertical joints that have created pillars and a notched crest geometry.



A) Planar Failure B) Wedge Failure C) Toppling Failure

Plate 2: Basic Failure Mechanisms in Rock Slopes (Hudson and Harrison, 1997[1])

Aside from toppling, there are two other smaller-scale mechanisms of cliff face failure: gravity falls and ravelling.

Gravity falls describe the vertical falling of overhanging pieces of rock from the rock faces. These failures occur as a result of differential weathering and erosion processes which can result in weakening and eventual removal of softer, more blocky layers below a more competent layer, resulting in an overhang. Evidence of past gravity falls was observed at Segment 11 in the form of small piles of crumbled rock in areas where the cliff face did not have an overhanging shape.

Ravelling refers to the failure of small individual pieces of deteriorated rock from a steep rock face. This generally occurs in more blocky rock faces where ice jacking and groundwater eventually displace small blocks of rock from the face. Because most of Segment 11 was observed to be blocky and somewhat undercut, ravelling failure was prominent and noted in many areas during the site investigation.

7.3 Stability Assessment of Slope Segments

There are a number of factors that affect the stability of the rock slopes in Segment 11. The main factors include: rock mass structure, weathering, and erosion. The current stability of the rock slope segments are mainly governed by the rock mass structure (i.e. jointing and bedding) and geometry of the rock faces (primarily overhangs) while the future stability will be affected by ongoing erosion and weathering of the rock mass. The ongoing erosion and weathering are largely the result of freeze-thaw action in the winter months that results in ice jacking, vegetation on the slopes which results in root jacking of the joints and fractures, wave action, and surface water runoff/groundwater seepage. The slope shows evidence of ongoing weathering and erosion in the form of undercut sections as well as degraded loose limestone blocks which can easily detach from the rock face. As weathering of this slope segment continues, the integrity of the exposed rock mass will continue to degrade and break apart. Consequently, the rock slope will continue to get closer to the edge of Highway 33 as the erosional processes continue.

[1] Hudson, J.A. and Harrison, J.P., 1997. Engineering Rock Mechanics, An Introduction to the Principles. Pergamon.

7.3.1 Rock Mass Structure

The discontinuities observed on site include near-horizontal bedding planes and steeply inclined to vertical joint sets. The horizontal bedding is the dominant structure within the rock mass with very thin to thin limestone beds interbedded with fissile shale. Due to the small spacing between the bedding planes, the discontinuities do not form blocks, but instead break apart into thin slabs and small flat boulders. The main failure mechanisms for this segment are gravity falls and ravelling in the case of overhanging rock, but toppling could also be an issue in the case of the numerous pillar formations created by the intersecting vertical joints.

Along this segment it was noted in the field that several vertical joints were consistently present in an orientation of about 070º to 095º strike. This indicates that the rock mass has a preferential plane of weakness or discontinuity in this orientation, with the potential to create pillar formations.

7.3.2 Weathering

Weathering refers to the process of breaking down of rock through influencing factors such as water, temperature, etc. Potential weathering processes include physical (mechanical), chemical or biological processes. Possible weathering processes that were identified at Segment 11 include the following:

Freeze-Thaw Cycles

When water is present in open fractures in rock, freezing of this water during cold weather can cause the fracture to 'jack' open due to the increase in volume. This leads to a larger fracture in the rock and more space for water to infiltrate during the next freeze-thaw cycle. Since some of the vertical cracks appear to propagate from road level ground surface down to the water elevation, this process is likely affecting these rock faces. Eventually rock fragments or blocks will become detached from the main rock face after enough freeze-thaw cycles.

Water

Water plays a significant role in rock face stability and most instability mechanisms are aggravated by the presence of water. On the investigated site, the following water sources were observed:

- In general groundwater levels in the rock mass will be seasonably variable. No significant areas of seepage were observed on the rock faces along Segment 11 at the time of the inspection.
- Although no surface water was noted on the day of the site visit, there is evidence of surface water on the rock face.

Vegetation

Vegetation can wedge or jack joints or fractures apart when its roots penetrate into an opening in the rock. This can also accelerate the problem of ice jacking because it creates a larger opening for water to infiltrate. Vegetation was observed at Segment 11 but did not seem to have a significant impact on the rock faces. Small trees located near the crest and on the slope close to the toe of the slope were observed but their root systems have not yet contributed to the initial jacking of the observed rock fractures.

7.3.3 Erosion

Erosion refers to the removal of soil or rock material through natural surface processes and subsequent transportation of this material to another location. Erosional processes such as wind and water flow can change the size and shape of a landmass over time. Possible erosional processes that are occurring at Segment 11 include wave action, ice scouring, and surface water run-off.

The undercutting observed at Segment 11 is likely the result of both wave action in the summer and ice scouring in the winter. The waves and ice appear to be the most dominant erosional process at this site and as such, any remedial action should attempt to mitigate the wave action and ice scour from eroding the rock slopes further.

Surface water run-off from the road and the top of the slope also contributes to erosion of the slopes. Although this erosional process is less dominant than the waves and ice, it still plays a role in the degradation of the slope.

Although there is clear evidence of ongoing erosion such as undercut areas, it is not clear what the current rate of erosion is over time. Since all three slope segments are already very close to Highway 33, it is unclear how much longer the erosion can continue before the road is compromised due to localized failures. Currently there are no areas where the depth of undercutting extends back as far as the roadway thereby undermining the road. As such, there are no imminent rock slope failures that might compromise the highway. Ongoing weathering and erosion, if left unchecked, will eventually reach the highway although this is not likely for a number of years.

8.0 REMEDIAL MEASURES

8.1 General

A summary of the potential remedial options and foundation engineering recommendations pertaining to Segment 11 is presented in the following sections. Based on the results of the visual site inspection and the LiDAR surveys, it is recommended that shore protection measures be installed along Segment 11 to prevent further erosion and slope stability failures and ensure the long-term stability of the adjacent highway. Remedial options for shore protection are presented with advantages and disadvantages for each option.

8.2 Remedial Options

Several options are available for the remediation of the rock slope at Segment 11. A comparison of the possible remedial options including a qualitative estimate of the effectiveness, constructability and durability of each measure, regulatory/environmental acceptance, and construction costs for each option was carried out. The comparison of the options is summarized in Table 3 in Section 8.3. The options are listed below and a brief description of each is provided in the sub-sections that follow.

- Do nothing;
- Monitoring;
- Relocation of Highway 33;
- Placement of beach fill;
- Placement of rip-rap;
- Rock or concrete revetments;
- Block gravity retaining walls (concrete or stone); and
- Concrete buttresses and rock bolts.

Option 1: Do Nothing

This option does not address any of the hazards identified during the slope inspection and does not ensure the long-term stability of the roadway. This option is not advisable for long-term stability of the slope segments and the highway as the slopes will continue to erode and will likely eventually undermine the roadway.

Option 2: Monitoring

Although the monitoring option does not address any of the hazards identified during the slope inspection and does not ensure the long-term stability of the roadway, monitoring of Segment 11 is a viable option in the short-term. This option would provide a better understanding of the erosion rates of the slopes while also ensuring that the slopes do not degrade past an adequate set-back for safe operation of Highway 33. Monitoring should consist of annual visual inspection and measurements of the crest location in the spring of each year to assess the rock slope conditions. LiDAR surveys should be conducted every three to five years (initially, with the possibility of adjusting the frequency based on the measured erosion rates) to monitor the change in the rock slope location in order to assess erosion rates. The proximity of the vertical joints to the road guardrail could affect the highway in the future as the slopes will continue to erode and could eventually undermine the roadway or guardrail. Fortunately, monitoring is a relatively low cost option with no significant constructability or environmental permitting issues. Monitoring is highly recommend for Segment 11, at least as an interim measure, if no other remedial option is implemented within the next two to three years.

Option 3: Relocation of Highway 33

Relocation of Highway 33 is a viable but relatively costly option to ensure the long-term stability of the roadway adjacent to Segment 11. This option would involve the relocation of the highway to a safe distance from the existing shore line, considering the long-term erosion of the slopes. The road relocation would have to be staged during construction to minimize the impact on traffic. This option does not address the slope stability, erosion, or rockfall hazards currently present at the site but removes the risk to the highway. The natural appearance of the shoreline would not be impacted by this option, but the costs of this option would be very high. Potential acquisition of land (principally farmland), environmental assessments, and permitting processes would add to the overall costs and schedule for this remedial option.

Option 4: Beach Fill

Beach fill, or soft protection, is not an option for Segment 11 as there is no beach exposed at this site; such an option is only viable for slope segments with an existing beach area along the shoreline.

Option 5: Rip-Rap

Placing rip-rap at the toe of the rock slopes is a viable option for erosion protection for Segment 11. Given that the majority of the erosion and undercutting is happening at the toe of the slopes, the addition of rip-rap would be a reasonable and natural-looking solution for slope toe remediation. A wave analysis would need to be carried out to determine the appropriate height and size of the rip-rap. The cost of this remedial option will be moderate. This option would, however, not address the open vertical cracks at the upper portion of the rock slopes and at the crest.

Option 6: Rock or Concrete Revetment

A rock or concrete revetment is also a viable option for the remediation of Segment 11. This option would involve cutting back of the existing rock slope and placement of fill material and armour stone or concrete cover to create a new slope. A pinned anchor stone at the slope toe would be installed to prevent the revetment from sliding. This option would require a significant cut back of the existing rock faces including removal of all loose and fractured rock to a stable rock cut prior to placing fill material and armour stone or concrete cover in front of the slopes. The rock revetment would have a moderate impact on the natural appearance of the slopes, whereas the concrete revetment would have a higher impact on the natural appearance of the slopes; on this basis, the rock armour stone is preferred over concrete. Environmental permitting with local conservation/environmental authorities would be required. The rock/concrete revetment option would address both the slope toe erosion as well as the erosion and open cracks at the top of the slope and would, therefore, ensure the long-term stability of the highway. Given the sloped configuration of this option the impact height and energy from waves would be reduced compared to a steep rip-rap or block retaining wall option. The cost of this option will be high initially but should require minimal maintenance.

Option 7: Block Gravity Retaining Walls

This option would involve the construction of a concrete or stone retaining wall in front of the existing slopes. A significant cut back of the existing rock faces would be required prior to construction of the walls, including removal of all loose and fractured rock to a stable rock face beyond the extent of the vertical discontinuities. Additional investigation would be required to confirm the geometry and rock conditions below the water, to provide a basis for the development of wall foundation recommendations. Retaining walls would have a high impact on the natural appearance of the slopes; however, the use of natural stone would reduce this impact. Environmental permitting with local conservation/environmental authorities would be required for this option. The retaining wall option would address both the slope toe erosion as well as the erosion and open cracks at the top of the slope and would ensure the long term stability of the highway. The costs of this option will be high.

Option 8: Concrete Buttresses and Rock Bolts

This option would involve construction of concrete buttresses at undercut areas to support overhanging rock above and to mitigate further erosion in the undermined areas. Large vertical openings or fractures could also be filled with concrete. Prior to construction of the concrete buttresses, any loose, unstable rock including the large blocky columns of rock would be machine-scaled to produce a relatively clean, stable rock face. Larger overhangs or columns of rock that cannot be removed by scaling would be trim-blasted or rock-bolted to remove or secure the unstable rock. Buttresses would be dowelled into sound bedrock both vertically and horizontally, and drainholes would be installed to provide drainage of the rock from behind the concrete. This option would address any existing overhangs, large open fractures and columns but would not mitigate ongoing erosion of areas not covered with concrete. Over time, additional undercutting may develop in areas of exposed rock that would require construction of additional buttresses/bolting, and the installed rock bolts will need to be tested periodically (every 10 years) and replaced if they corrode.

8.3 Comparison of Remedial Options

The advantages and disadvantages of each option have been assessed based on the capital cost of the construction, the life cycle cost of maintenance of the remedial work or repairs to the highway, the effectiveness of the remedial option and the likelihood of obtaining the necessary permitting that would be required. Table 3 provides a summary of this assessment. In this table each category was given a relative ranking between 1 and 6, with 1 being the worst scenario and 6 being the best scenario. Each category was also given a weighting in the form of a percentage depending on the importance of each factor which are multiplied against the rating given and summed to obtain an overall score out of 6. Scores below 3 are coloured ‘red’ to indicate that they are not a recommended solution. Scores of 3 to 4 are 'yellow' as they could be considered but have some limitations and therefore are not the best remediation options. Scores greater than 4 are 'green' to indicate they are a recommended solution(s).

Table 3: Risk Rating Matrix for Slope Remediation Options

Remediation Option	Capital Cost (20%)	Life Cycle Cost (10%)	Effectiveness (40%)	Environmental Permitting Requirements per Conservation & Environmental Authorities (30%)	Overall Score (out of 6)
Option 1: Do Nothing	6	6*	1	6	4.0
Option 2: Monitoring	5	6*	2	6	4.2
Option 3: Relocation of Highway 33	1	6	5	1	3.1
Option 4: Beach Fill	3	2	1	3	2.1
Option 5: Rip-Rap	4	4	4	5	4.3
Option 6: Rock/Concrete Revetment	3	5	6	4	4.7
Option 7: Block Gravity Retaining Walls	2	5	6	2	3.9
Option 8: Concrete Buttresses and Rock Bolts	4	3	4	5	4.2

* Both the Do Nothing and the Monitoring options have no direct life cycle costs but over the design life of the highway it is likely that, if no other remedial option is implemented and the erosion continues and eventually undermines the highway, the highway would require significant repair work.

8.4 Recommendations

Option 6 – Rock/Concrete Revetment has the best overall ranking and should therefore be considered the preferred remedial option. In order to keep the look of the coast natural, and potentially reduce the environmental permitting costs, the rock revetment option would be preferred over the concrete revetment option (see Plate 3). If the mitigation measures are not implemented within one to two years, then it is recommended that annual monitoring of the rock face be carried out in the interim, with the next visual inspection in the Spring. For this option, if the wave action or lake level changes in this area are too great, some maintenance may be required over the long term; however, if designed and implemented properly, this maintenance cost should be relatively small. Rock excavation and rock scaling should be carried out in accordance with OPSS 202. Loose or unstable rock should be removed prior to constructing the revetment.

Plate 3: Typical Stone Revetment in Place along Highway 33

Use of Option 5 – Rip-Rap or Option 8 – Concrete Buttresses and Rock Bolts could also be considered as alternatives.

The monitoring option also scored relatively high and could be considered as an option to defer remedial work since the rate of erosion is somewhat unknown. It is possible that the rate of erosion is very slow and that remedial work could, in that case be deferred for a long period of time (potentially 5 to 10 years or more). This option does, however, carry a risk that erosion rates could be higher than expected and remedial work may need to be implemented sooner than anticipated.

9.0 CLOSURE

This Foundation Design Report was prepared by Sarah Pidgen, P.Eng., and reviewed by Mark Telesnicki, P.Eng., a senior rock mechanics engineer and RAQS Rock Hazard Specialist at Golder. Lisa Coyne, P.Eng., a Designated MTO Foundations Contact for Golder, conducted an independent quality review of the report.

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Senior Rock Mechanics Engineer

Lisa Coyne, P.Eng.
Principal, Designated MTO Foundations Contact

SP/MJT/LCC/sp/jl

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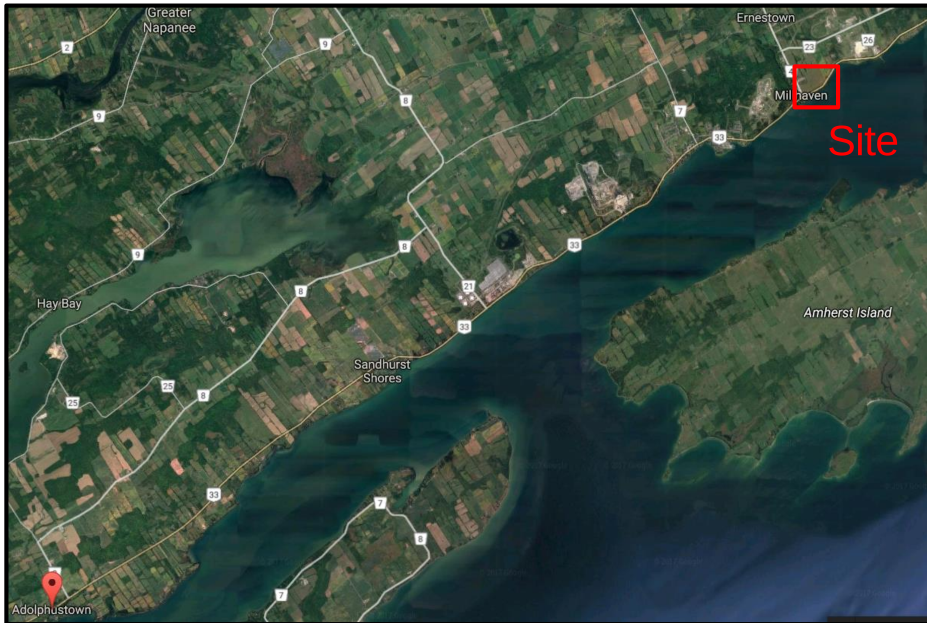
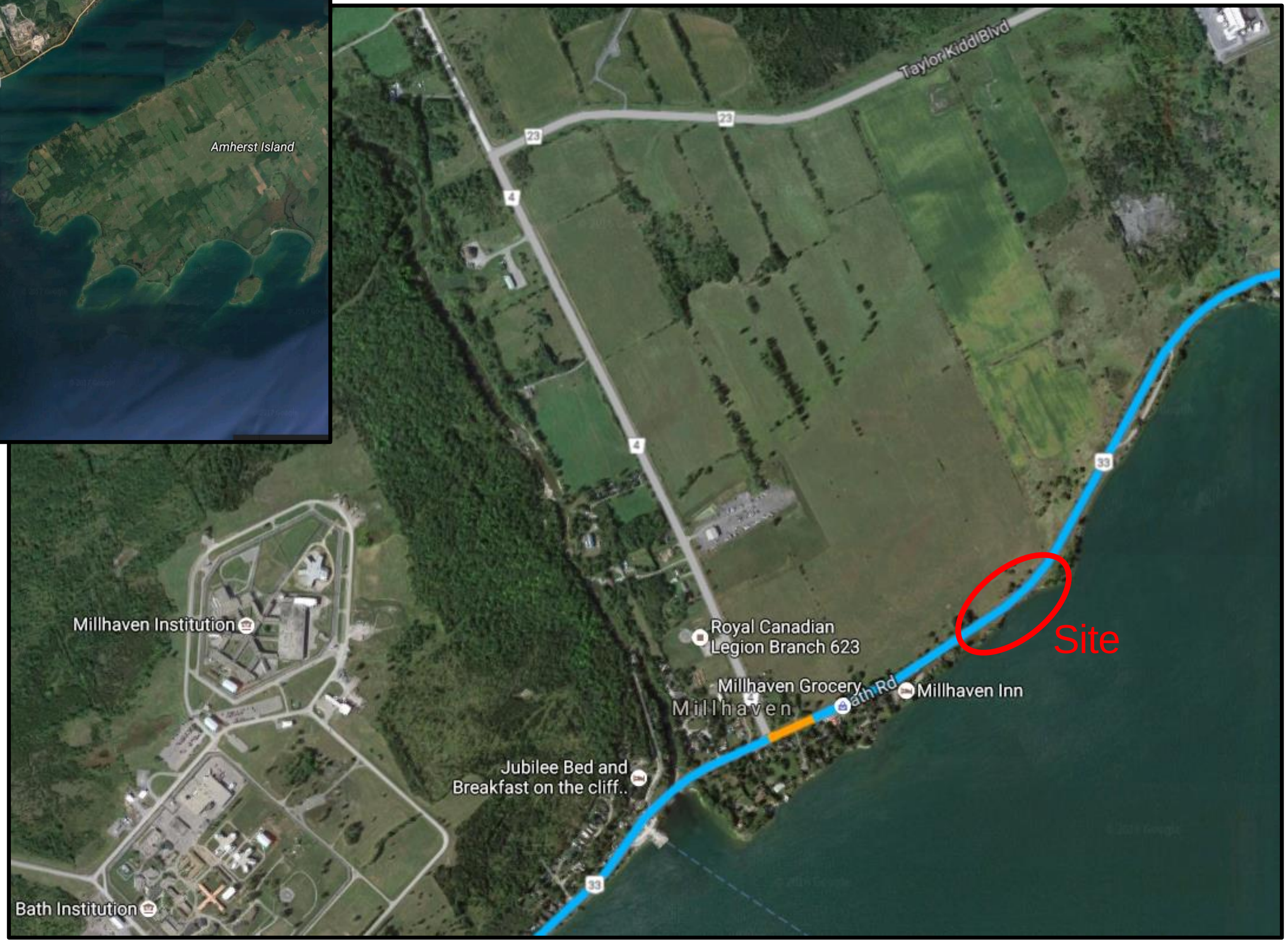
FIGURES





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PROJECT
Highway 33 Slope Inspection - Slope Segment 11

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-07-12
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DESIGN	XX
REVIEW	MJT
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TITLE
Site Location Plan

PROJECT No.
1413191-1140

1

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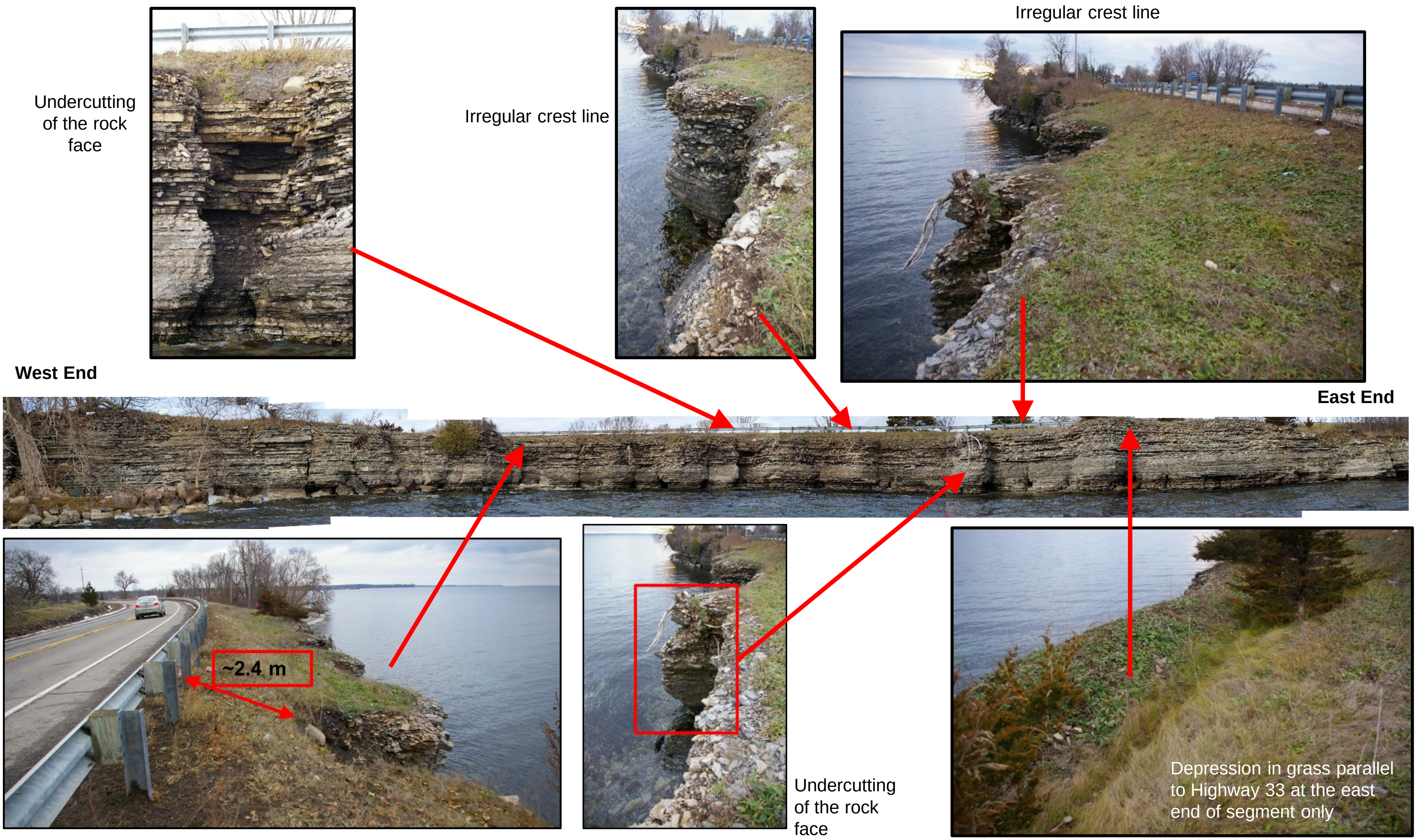

Crest of eroded rock face is about 2.4 m from the guardrail of Highway 33.

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Highway 33 Slope Inspection - Slope Segment 11

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TITLE
Overall Rock Slope Conditions

PROJECT No.
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2

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Highway 33 Slope Inspection - Slope Segment 11

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TITLE
Typical Rock Slope Profiles and Slope Composition

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1413191-1140

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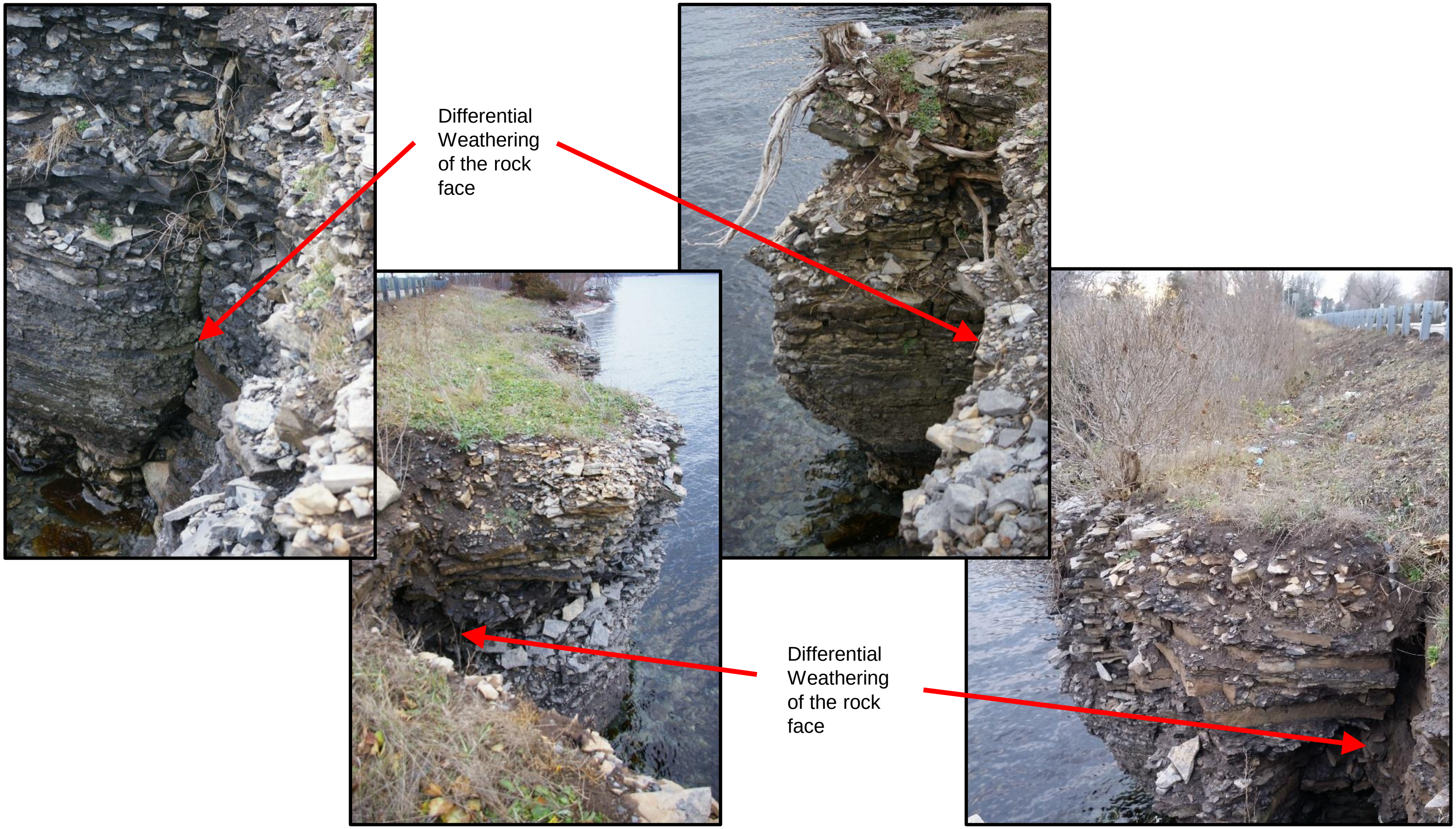

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Ministry of Transportation Ontario		Highway 33 Slope Inspection - Slope Segment 11

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REVIEW	MJT
APPROVED	MJT

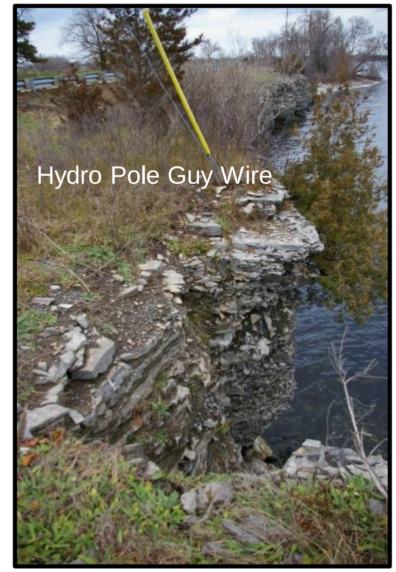
TITLE

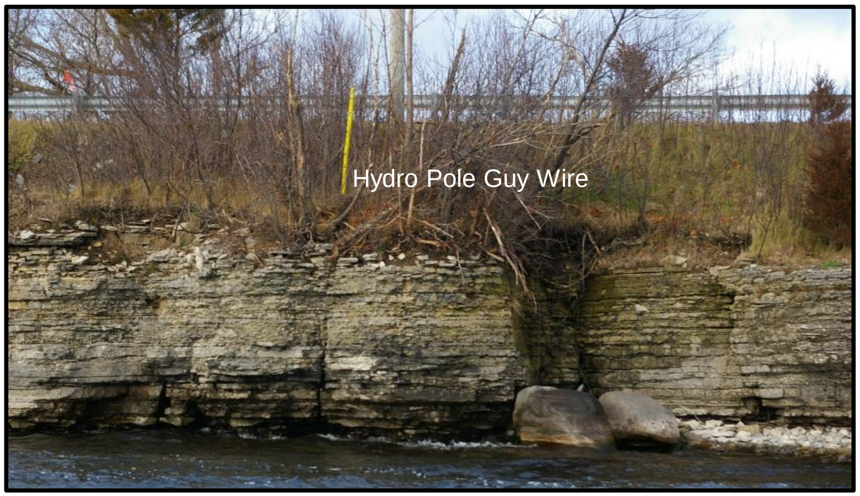
Details of Differential Weathering of Rock Face

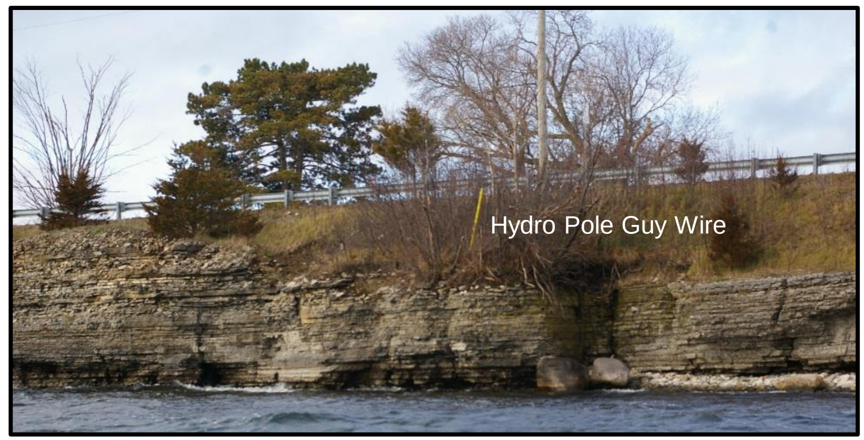
PROJECT No.

1413191-1140

4







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REVIEW	MJT
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TITLE

Hydro Pole and Guy Wire Anchored to Overhanging Rock

PROJECT No.

1413191-1140

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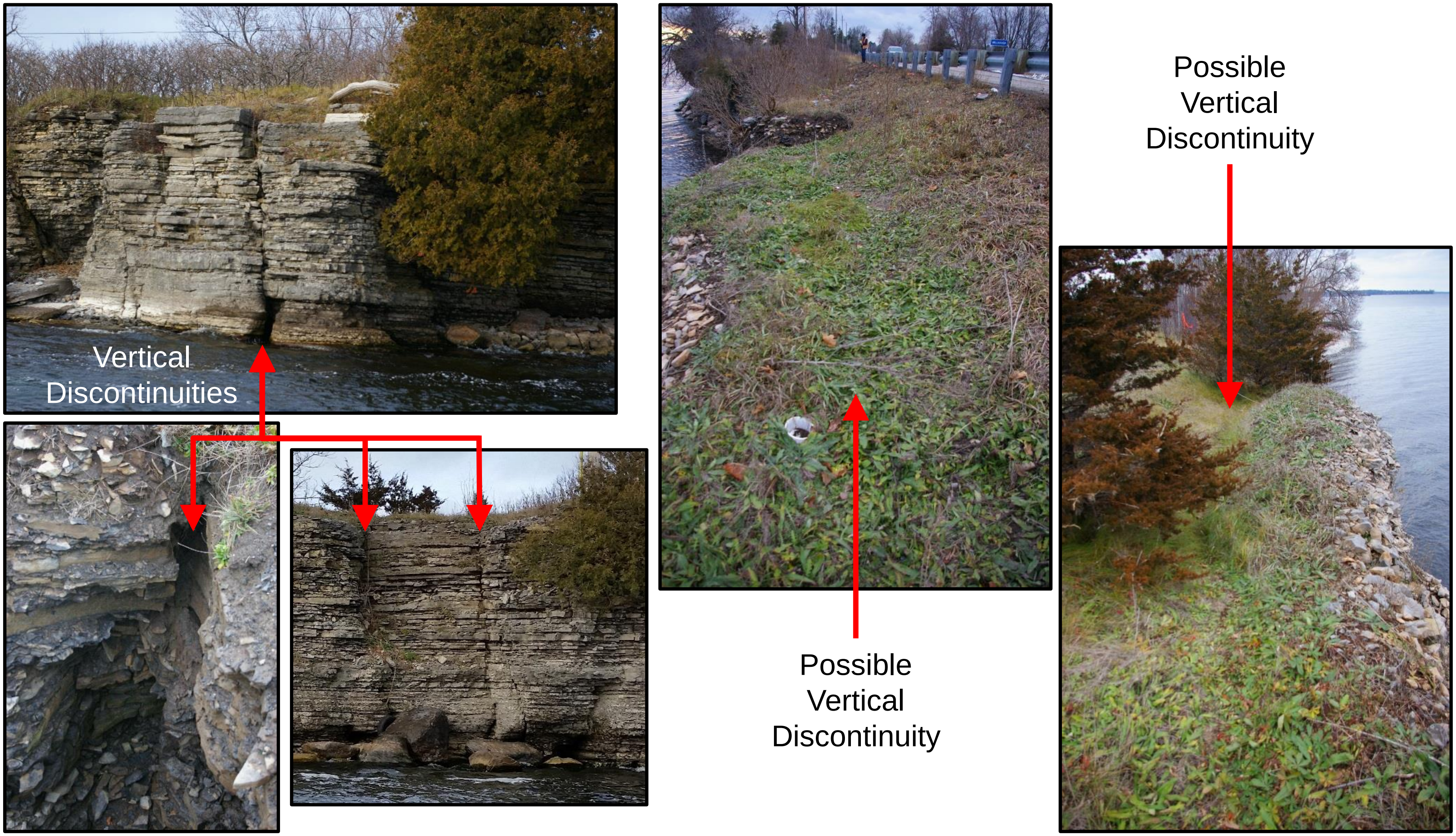

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CONSULTANT Golder Associates	YYYY-MM-DD: 2017-07-12 PREPARED: AB DESIGN: XX REVIEW: MJT APPROVED: MJT	TITLE Large Open Discontinuities along Rock Slope	
		PROJECT No. 1413191-1140	6

CLIENT
Ministry of Transportation Ontario

PROJECT
Highway 33 Slope Inspection - Slope Segment 11

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REVIEW	MJT
APPROVED	MJT

TITLE
Trees and Vegetation Growing in Open Discontinuities

PROJECT No.
1413191-1140

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PROJECT
Highway 33 Slope Inspection - Slope Segment 11

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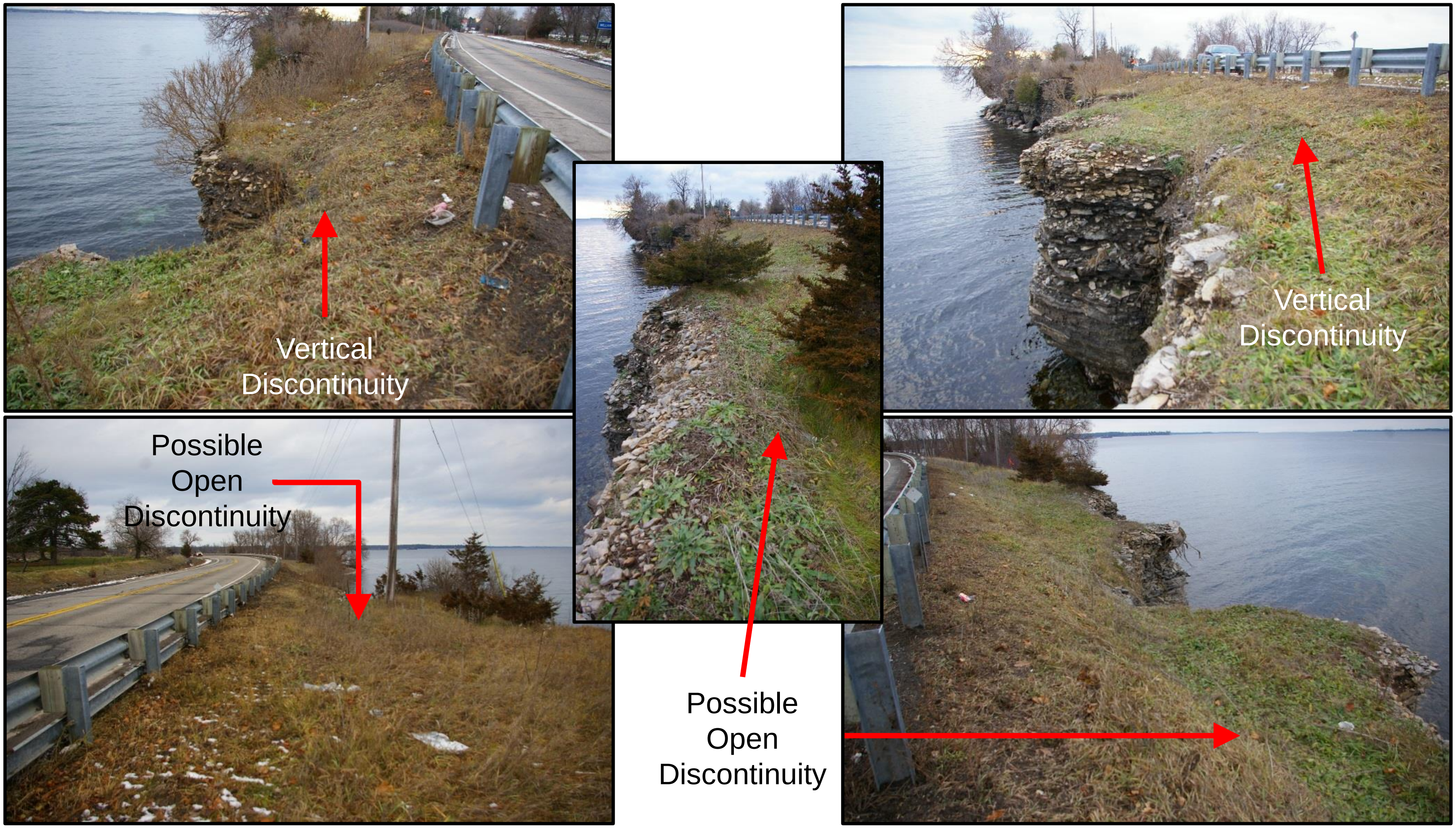
APPROVED	MJT

TITLE
Typical Distances Between Slope Crest and Highway

PROJECT No.
1413191-1140

8



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Highway 33 Slope Inspection - Slope Segment 11

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APPROVED	MJT

TITLE
Surface Depressions Due to Open Discontinuities

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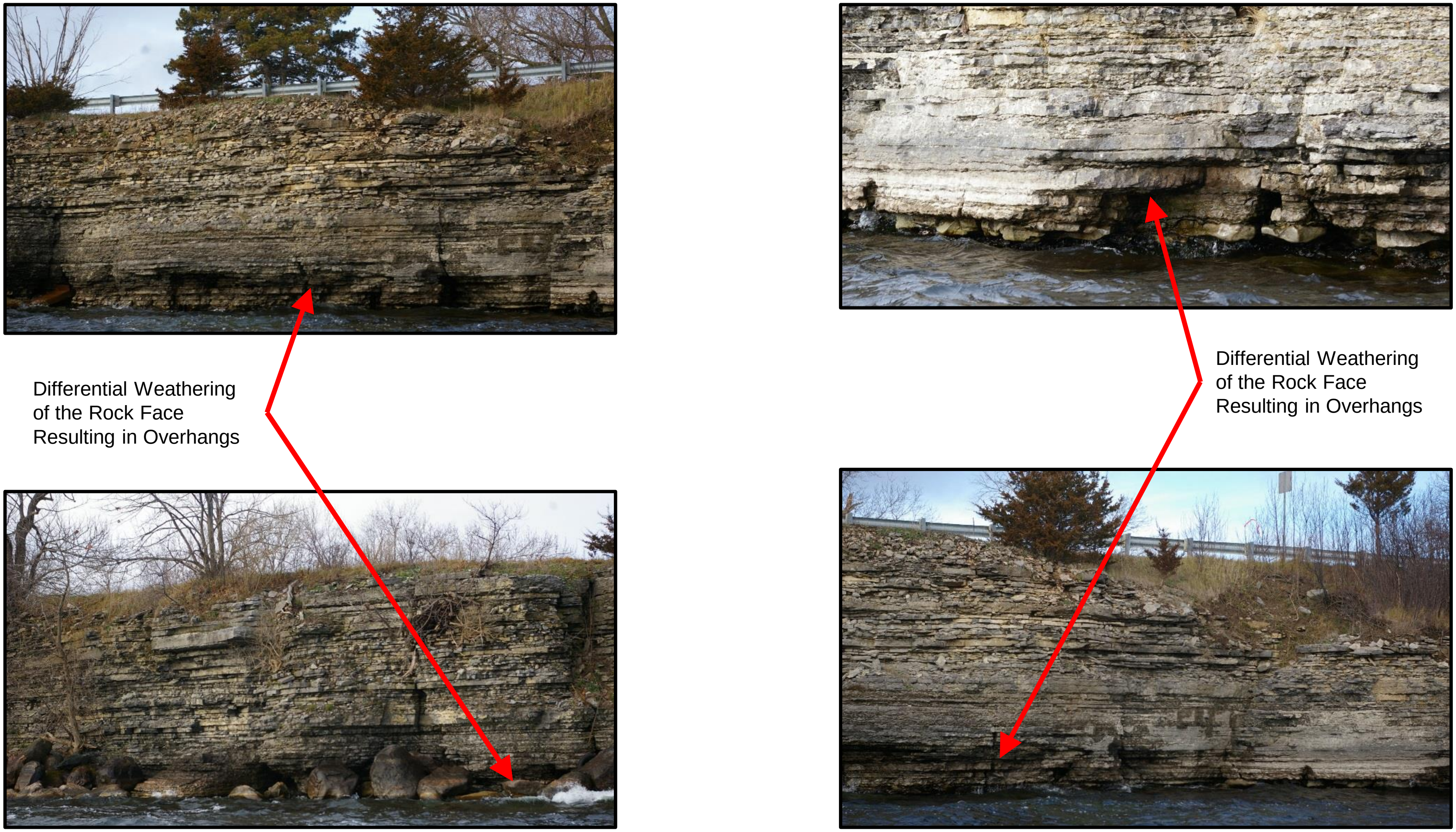

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Golder Associates	YYYY-MM-DD	2017-07-12
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TITLE

Undercutting Due to Differential Erosion of Rock Face

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1413191-1140

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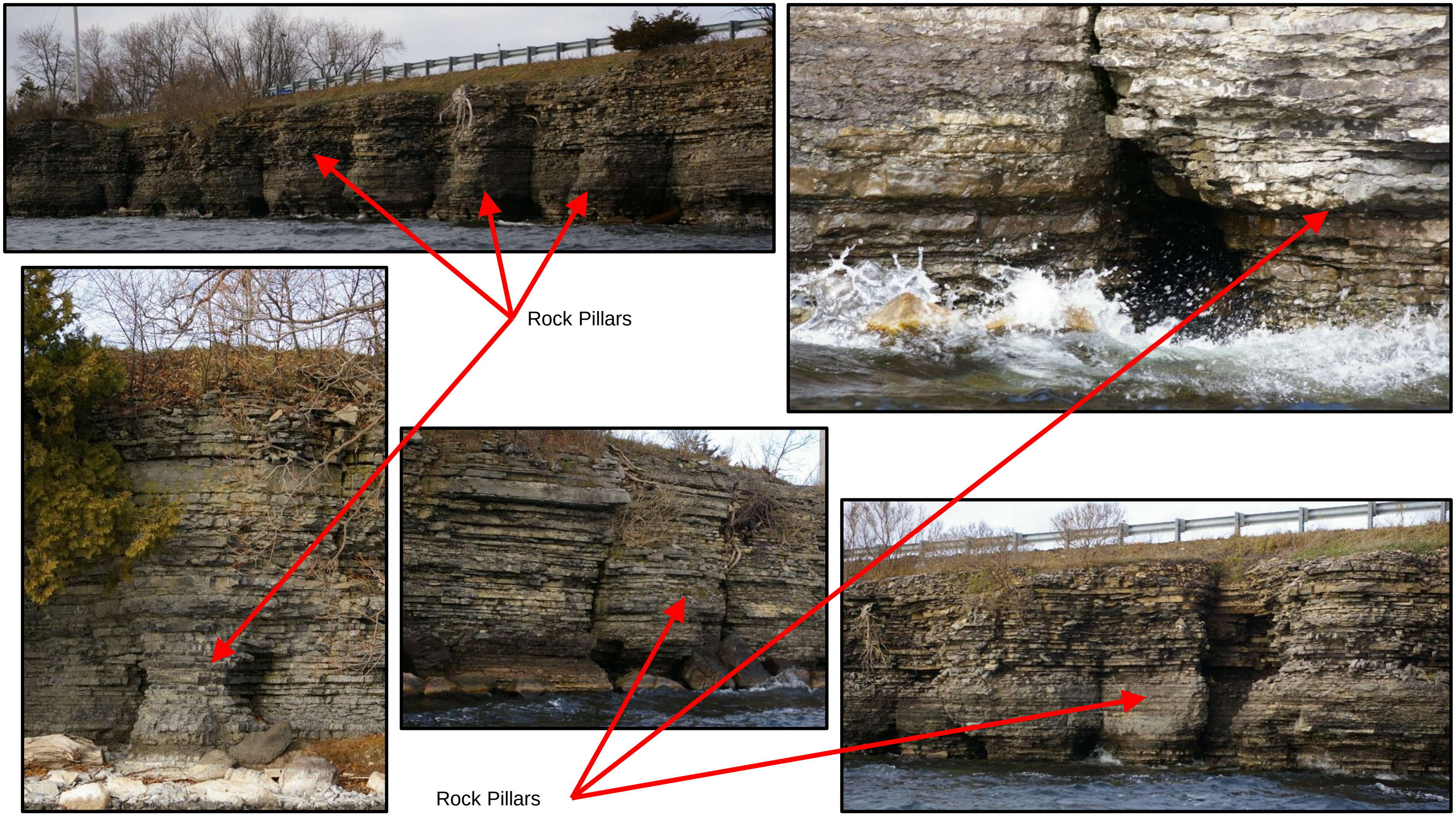

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Highway 33 Slope Inspection - Slope Segment 11

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TITLE
Caves and Pillars due to Differential Erosion of Rock Face

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1413191-1140

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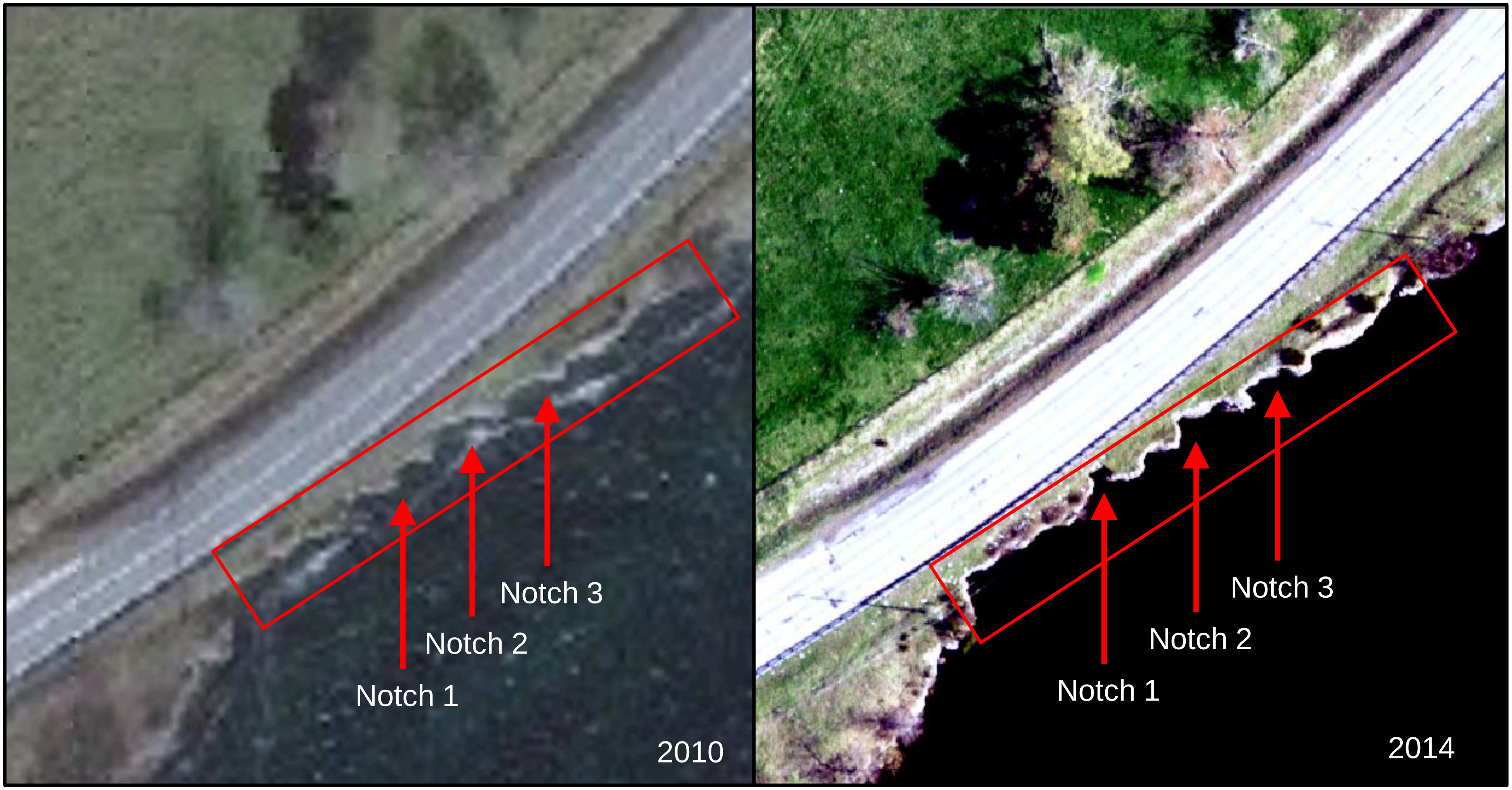

CLIENT	PROJECT
Ministry of Transportation Ontario	Highway 33 Slope Inspection - Slope Segment 11

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REVIEW	MJT
APPROVED	MJT

TITLE

Results of Imagery Analysis Showing Previous Slope Failure

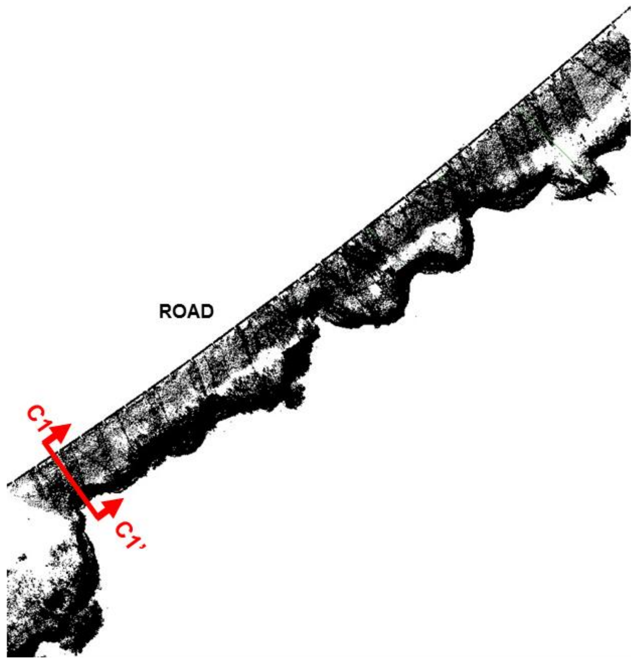
PROJECT No.

1413191-1140

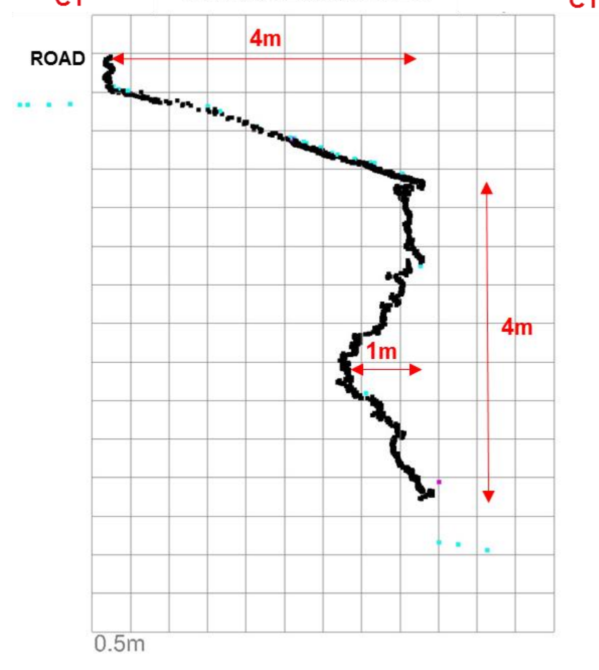
12

PLAN VIEW OF GOOGLE EARTH

PLAN VIEW OF LIDAR



CROSS SECTION VIEW



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CONSULTANT Golder Associates	TITLE Cross Section C1 to C1'

YYYY-MM-DD	2017-07-12
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REVIEW	MJT
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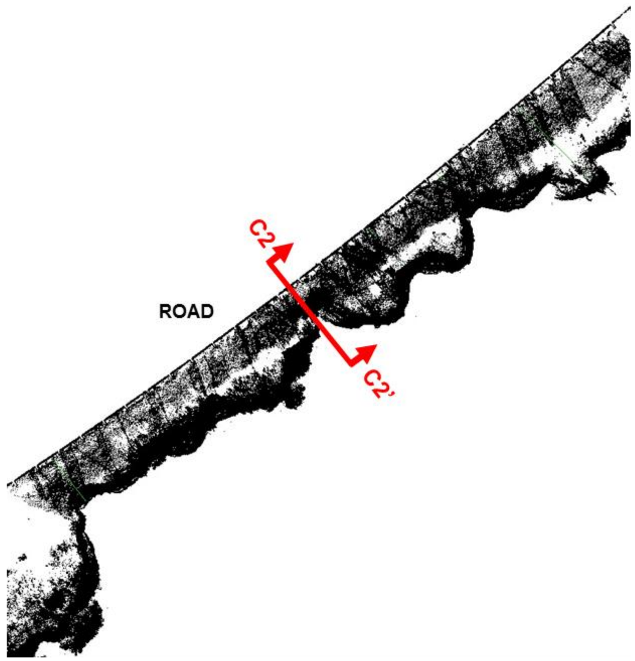
PLAN VIEW OF GOOGLE EARTH

PLAN VIEW OF LIDAR



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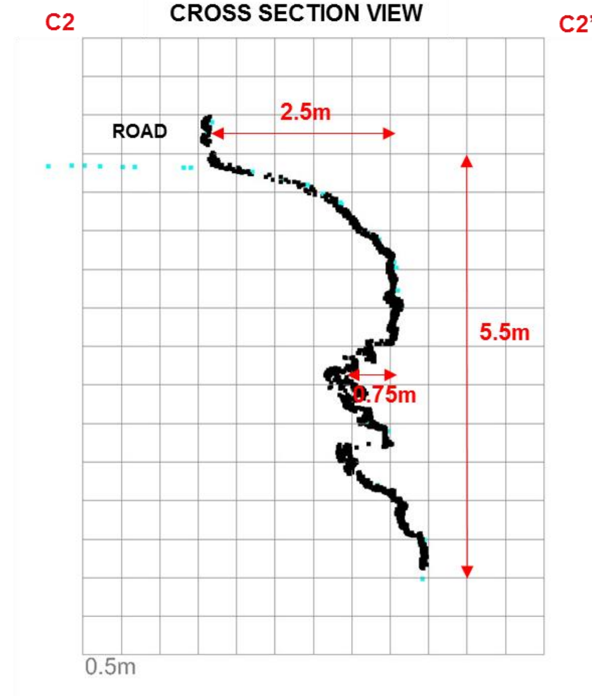

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TITLE
Cross Section C2 to C2'

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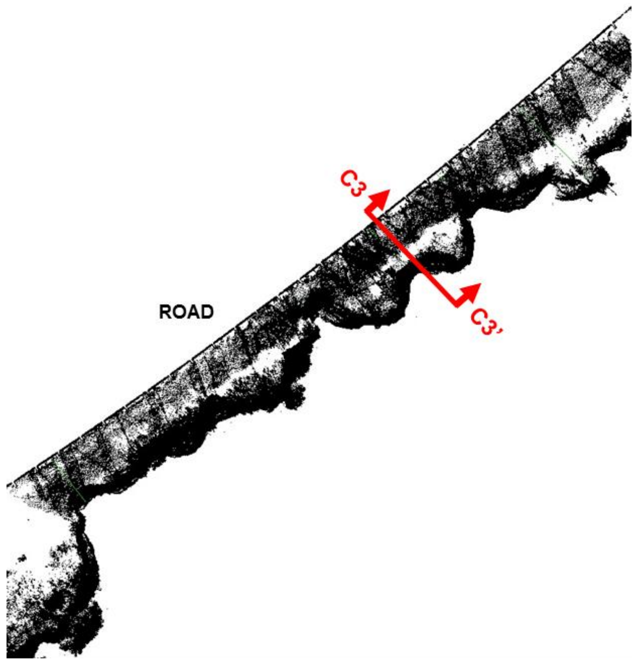
PLAN VIEW OF GOOGLE EARTH

PLAN VIEW OF LIDAR



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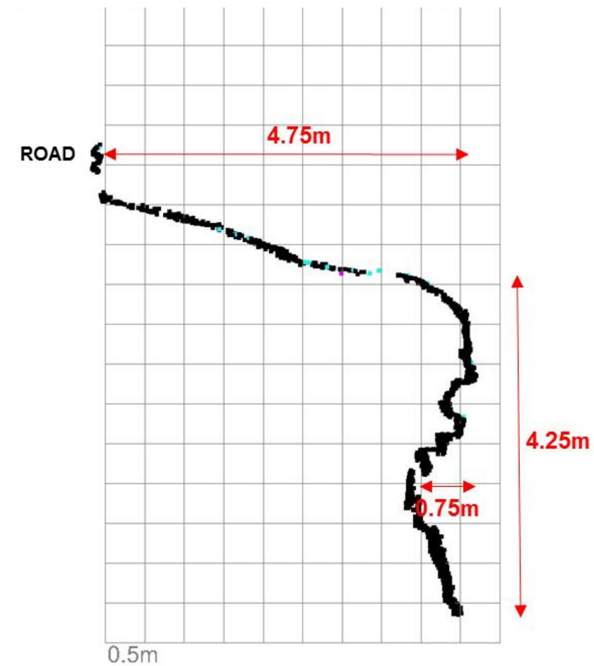

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CONSULTANT Golder Associates	TITLE Cross Section C3 to C3'
YYYY-MM-DD: 2017-07-12 PREPARED: AB DESIGN: XX REVIEW: MJT APPROVED: MJT	PROJECT No. 1413191-1140
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PLAN VIEW OF GOOGLE EARTH

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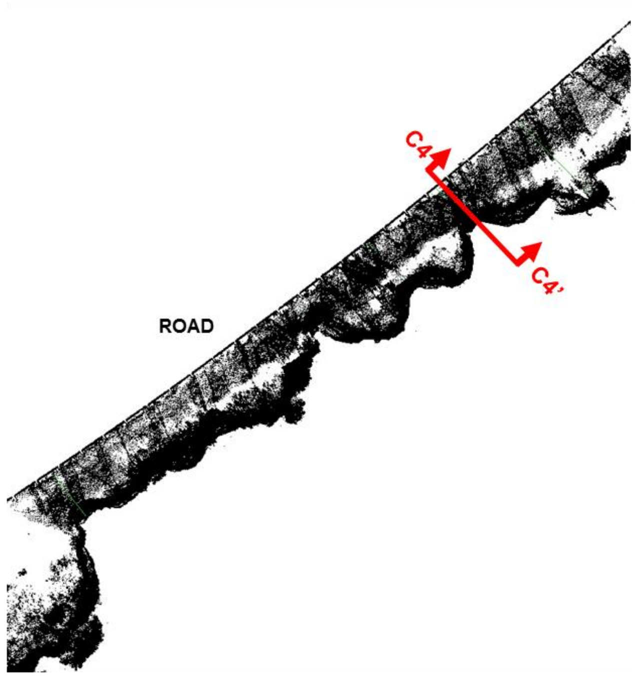

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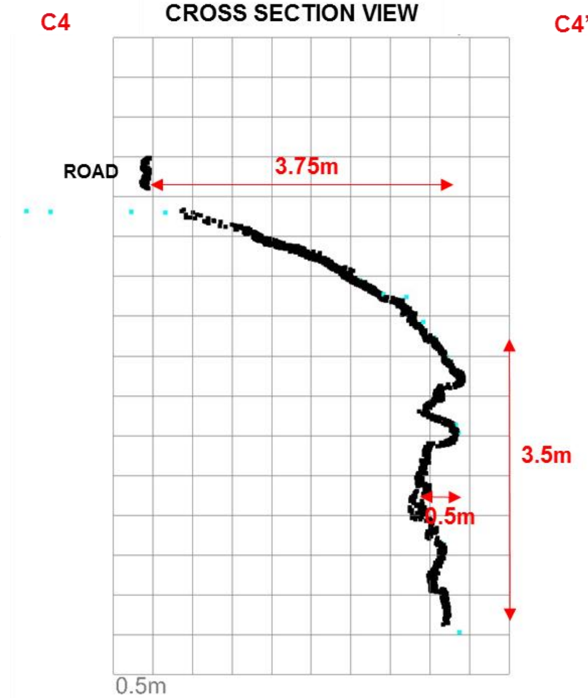

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TITLE
Cross Section C4 to C4'

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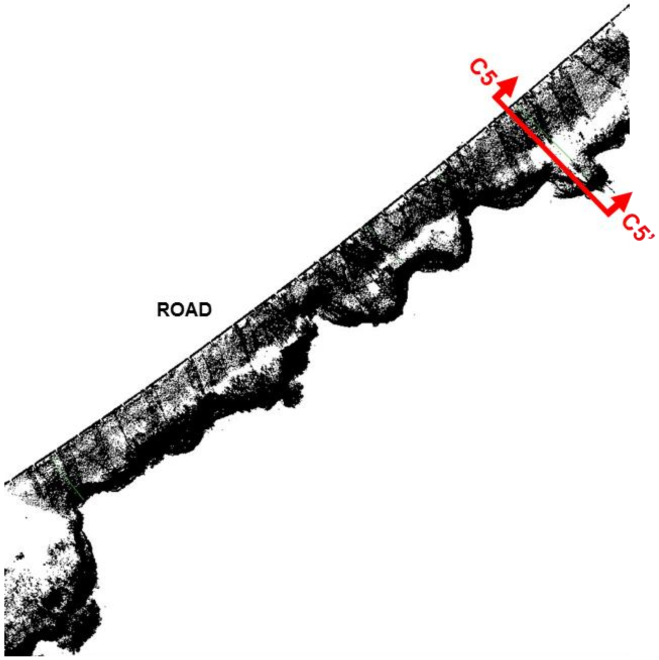
PLAN VIEW OF GOOGLE EARTH

PLAN VIEW OF LIDAR



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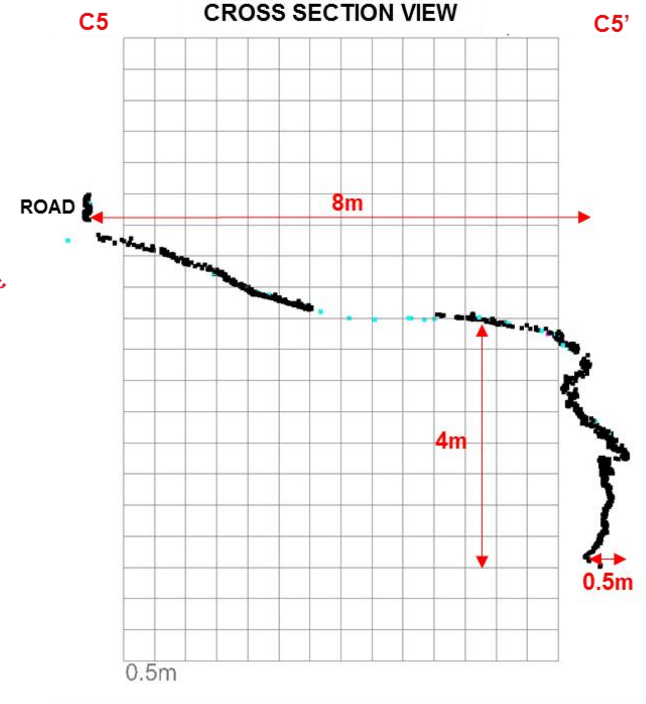

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TITLE

Cross Section C5 to C5'

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