Memorandum Report

Date: April 2, 2012

Subject: Remedial Measures for Embankment Instabilities
Hwy 406 Northbound Approaching Westchester Avenue
W.O. 2012-11003
GWP 2364-09-00
GEOCRES No. 30M3-274

MERO Pavements and Foundations Section was requested by Shawn Smith of Central Region (CR) Planning and Design Office (P&D) on February 16, 2012 to provide recommendations for remedial measures for embankment instabilities at the east edge of the northbound embankment of Hwy 406 approaching Westchester Avenue, just south of the Westchester Avenue exit ramp. The St. Catharines Golf and Country Club is situated on the west side of Hwy 406. It is intended to incorporate recommendation into the Pavement Rehabilitation Project GWP 2364-09-00.

In response to the CR request, Project Foundations Engineer Fiona Leung, Foundation Design Technician Danny Tari and Foundations Co-op Student Diana Gomez Rodriguez visited the problem site with CR Contract Office Niagara Area Maintenance Coordinator Tymen Evink on February 28, 2012. Tymen Evink identified that there are three separate embankment instability areas (See Figure 1).

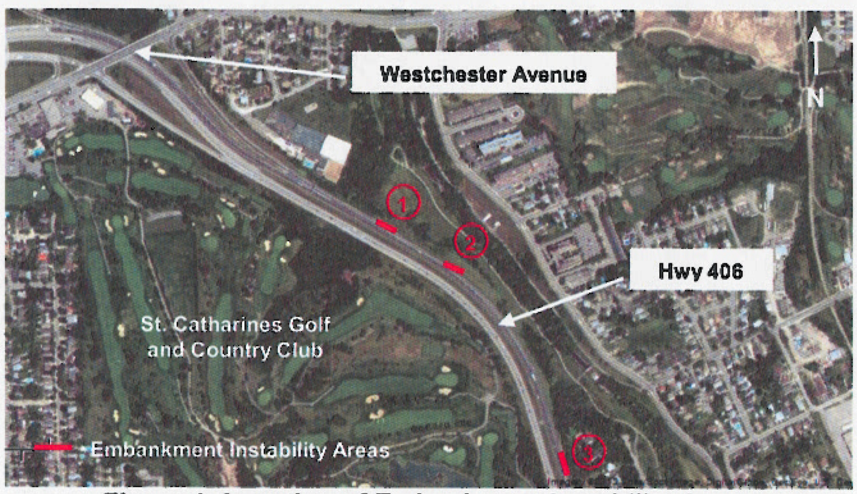

Figure 1: Location of Embankment Instability Areas

Based on the station reference number from GWP 2364-09-00, these areas are located:

1. from Station 28+715 to Station 28+760, approximate 45 m long
2. from Station 28+630 to Station 28+680, approximate 50 m long
3. from Station 28+280 to Station 28+305, approximate 25 m long

Figure 2 illustrates the typical slope problems in these areas.

Figure 2: Sample of the Problem Areas

Actual cross-sections illustrating the geometry of the instabilities were requested from CR P&D but were not available so that the current analysis by MTO Foundations Group has been based on assumed geometry from observations and existing base plans.

According to the base plan drawings provided by CR, the problem areas of Hwy 406 are near side slopes that are approximately 5m to10m high with a design slope geometry of approximately 2H:1V to 2.5H:1V. The crown of the road is located at the centreline or just east of the centreline. Crossfall from the crown is approximately 5% to the east edge of pavement. From the edge of pavement to edge of paved shoulder, the crossfall is approximately 7%. From the edge of paved shoulder to edge of granular rounding, the crossfall is steeper and up to an estimated 10% to15%. The granular upper portion of the slope including the rounding is approximately 1.2m to1.5m deep by 1m to1.8m wide from the edge of shoulder depending on the location. The existing distressed side slopes are approximately 1.2H:1V (estimated by visual inspection), which is much steeper than the 2H:1V to 2.5H:1V indicated on the base plan in the problem areas. The side slopes below the upper granular portion and rounding as well as the bottom of the embankment are covered by vegetation (including swale vegetation and grass).

There are no catch basins nor curbs and gutters, but there are drainage ditches along the median and at the toe of slope at the problem areas. Partial surface runoff flows to the median ditch and partial surface runoff flows over the side embankment and then to the bottom drainage channel. It is noted that all three problem areas are located at low points of the highway grade and that some of the surface runoff follows the natural drainage path to flow over these embankment slopes to the bottom ditch. This is partly caused by the drop off at the rounding increasing the amount of flow overtopping the edge of the embankment. At the time of the site visit, the top layer of soil along the side slopes in these areas was noticeably moister than at other areas.

Steel beam guide rails (SBGR) are installed between station 28+150 and station 28+850 along Hwy 406. According to the OPSD 912.140 SBGR wood post assembly installation, the minimum buried depth of the SBGR wood pole is 1.2m. By observation, the width of the SBGR is approximately 0.3m wide and the width of the rounding from the edge of shoulder is approximately 1m wide. In some areas, the SBGR are tilted away from the road. This indicates that at least the top 1.2m of the embankment material is disturbed and causing the SBGR to tilt.

Base-mounted conventional lightings are installed behind the SBGR along Hwy 406. According to the OPSD 2200.01 concrete footing for base-mounted lighting, the maximum buried depth of the lighting pole foundation is 3.05m. The upper portions (approximately 0.5m) of these concrete bases for lighting are exposed, but there is no visible movement or tilting. Based on this observation, there is no deep seated failure that would pass below the base of the pole foundations. Although there is a 35-m long with 50mm to 75mm wide longitudinal pavement crack along the pavement shoulder (1.5 m away from the SBGR) from station 28+705 to station 28+740 and minor pavement shoulder settlement, it is not considered to be a sign of deep-seated slope failure.

From the conversation with Tymen, he indicated that the distresses at the top 1.5m of the slope areas (granular material) have been an issue for at least five years. The sides of the granular rounding have been eroded and the erosion has undermined the SBGR and exposed the top portion of concrete bases of light poles. In response to this distress, the CR maintenance contractor placed 'Granular A' around these areas in order to stabilize them and to prevent further undermining of the SBGR and lighting concrete bases. Those 'Granular A' materials were first placed five years ago and again recently in the week of February 8, 2012. However, by observation, there are no visible slope failures apparent within the vegetated areas below the granular zone.

Previous MTO Foundations Engineering studies (Geocres records 30M3-47 and 30M3-124) conducted in the early 1970's indicated that embankment slope instabilities occurred in this general area over the full vertical extent of the embankment. The embankment material was determined to be firm to stiff clay with organic inclusions. The natural subsoil consisted of stiff to very stiff silty clay. Those failures resulted in partial removal of the highway fill material accompanied by the development of wide cracks at the top of the embankment. It was concluded that those instabilities were caused by seepage forces acting at the contact surface of the fill material and the original subsoil and by the presence of very soft organic deposits between the original ground and subsoil and also by erosion by surface water. Those seepage pressures were attributed to the freeze-thaw cycles of the spring thaw, aggravated by heavy precipitation. The recommended remedial measures were to control seepage forces and surface erosion and consisted of

- removing the failed material and the soft material and any underlying organic deposits encountered
- placing a granular blanket of at least 300 mm thickness under any new fill
- installing counterfort drains with a minimum base width of 0.5m and filled with Granular A located, transversely at about 10 m intervals
- installing a discharge pipe at the north limit of the instability area to drain a nearby catch basin that existed at that time (it is not known if that catch basin still exists)

Based on the visual observations and previous Foundation Engineering studies, it can be concluded that

- the current instabilities of the embankment are surficial failures, as opposed to deep-seated failures through the natural subsoil below the base of the embankment
- the surficial failures are triggered by loss of confinement of the upper road bed material aggravated by uncontrolled surface runoff over the slope and to a lesser extent by the development of excess pore water pressures causing loss of soil strength due to the slope material being saturated with water
- the failure zones are isolated in the upper 1.5m of granular rounding/embankment
- erosion by surface runoff caused loss of lateral support of the top layer of the embankment and consequently pavement cracking and undermining and tilting of the SBGR

- the fact that the lighting pole basis did not tilt supports the conclusion that this is not a deep seated failure

In summary, the causes of the instabilities are not considered to be deep seated failure or to excess pore pressures acting on the slope and aggravated by uncontrolled surface runoff as was concluded for previous instabilities. Those previous instabilities were repaired and the slopes were stabilized. The cause of the current instability is a lack of confinement of the road bed materials due to unstable geometry caused by a lack of space in the transverse direction. The proposed new remedial measures then focus on establishing a stable geometry of the upper 1.5m or so the embankment combined with controlling surface runoff to minimize erosion.

Despite the surficial failures, there is no immediate danger to the embankment provided that the SBGR provides effective protection. Until a more permanent fix is implemented, the problem areas will continue to be destabilized by lack of confinement and by surface runoff, especially during the spring-thaw season and also during periods of heavy precipitation, which could further undermine the SBGR and lighting pole bases.

Based on the conditions at the problems sites, remedial solutions include increasing the lateral support at the upper embankment slope and controlling surface runoff. All pavement cracks shall be repaired to prevent water seepage and development of excess pore water pressures at the problem areas. The following remedial measures to increase the lateral support at the embankment are proposed for consideration:

- Option 1: reconstruct the entire embankment to permit flatter geometry at upper granular portion,
- Option 2: re-grade only the upper portion of the embankment (granular zone) to a flatter slope,
- Option 3: install a retaining soil system at the upper portion of the embankment (granular zone)

Option 1: Reconstruct entire embankment to permit flatter geometry at upper granular portion

Option 1 is a permanent term solution with low risk for reoccurrence option. It increases the lateral support to the embankment by flattening the entire embankment slope (no steeper than 2.5V:1H including space for the road bed). However, based on the visual observation and base plan drawing, there may not be sufficient space to implement this option. Therefore, surveying of the actual geometry would be required to confirm if there is enough property to extend the slope base. Soil investigation and engineering analysis would be required to detail the design. This option would disturb the existing stable slope unnecessarily and it may become an environment concern by removing stable vegetation along the embankment. Both construction cost and time perspectives would be high and the construction could affect the traffic on Hwy 406.

Option 2: Re-grade only the upper portion of the embankment (granular zone) to a flatter slope

Option 2 is an intermediate to permanent term solution with projected moderate risk of reoccurrence. It would limit reconstruction to only flattening the upper granular zone of the embankment (no steeper than 2V:1H, but preferred 2.5H:1V). However, based on the visual observation, there is insufficient space to implement this option with the current cross-section. Therefore, the entire embankment would have to first be widened (See Option 1). Another option is to reduce the width of the existing paved shoulder in order to construct a flatter slope for the granular zone. This option would require surveying of the actual geometry to confirm that there is enough space to construct a flatter slope at the granular (road bed) zone without disturbing the stable vegetation portion of the slope. Re-installation of the SBGR properly would be required because of the change of grade at the rounding. Additional soil investigation may not be required assuming that a conventional re-grading design would be provided. However, traffic interruption and the possibility of reducing the width of highway should also be taken into account. The construction cost and time would be medium range. Traffic interruption would be significant due to reconstruction of paved shoulder.

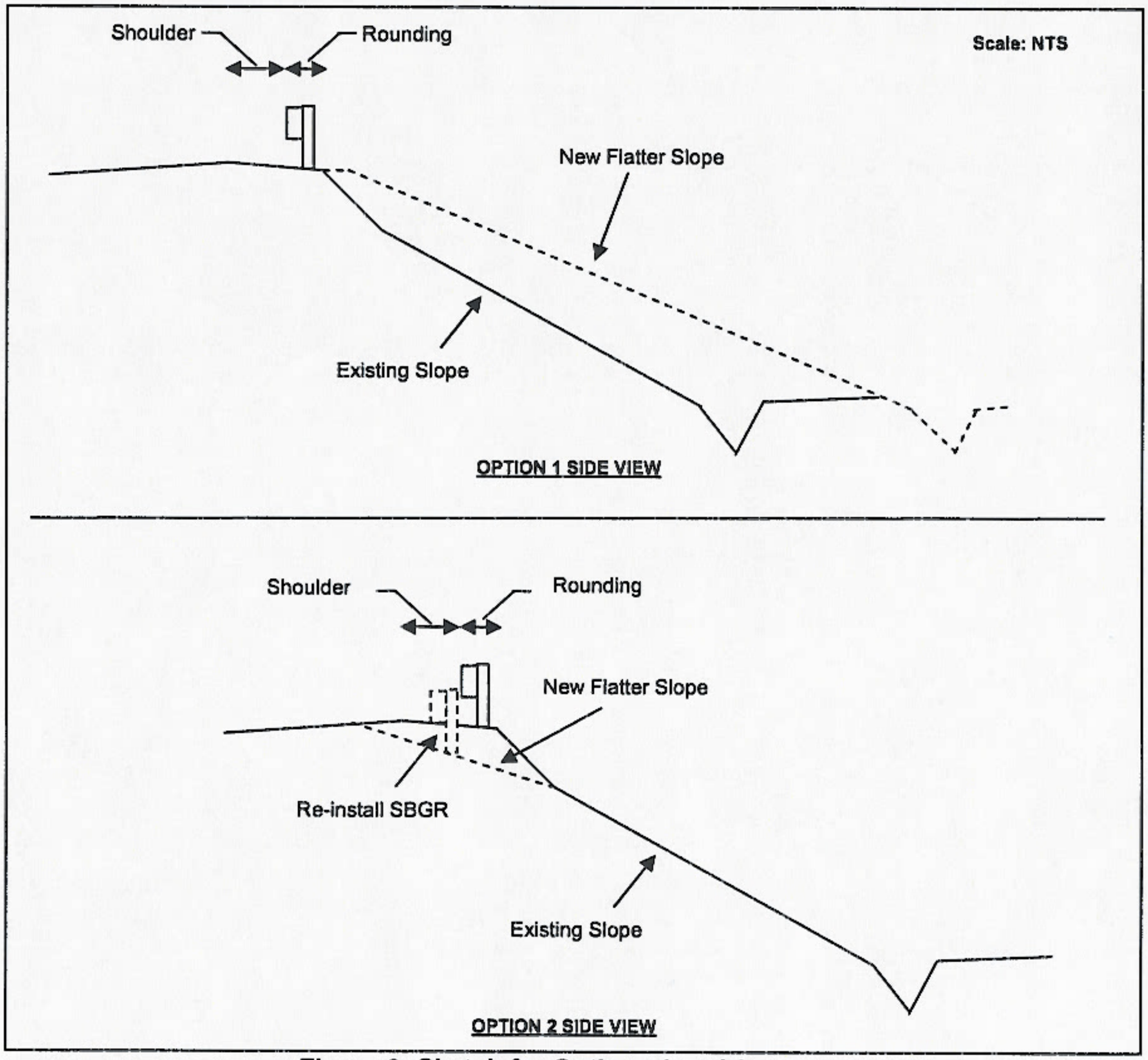

Figure 3: Sketch for Options 1 and 2

Option 3: Install retaining soil system at the upper portion of the embankment (granular zone)

This is considered to be a permanent term solution with projected low risk of reoccurrence. Detail soil investigation and retaining soil system design (such as Retaining Wall/Reinforced Slope) recommendations are required to provide sufficient lateral resistance to the top portion of the slope. This option would also require surveying of the actual geometry for the slope design and detail drainage design corresponding to the selected retaining soil system type. The construction cost and time for this option would be higher than Option 2, but less than Option 1. Traffic interruption could be significant depending on the extent to which excavations encroach on the highway.

Supplemental Drainage

Options 1 and 2 would require design and incorporation of drainage control systems. The drainage control system is used to control the surface runoff and reduce speed of water flowing in an uncontrolled manner over the problem areas. The drainage control system design could be replacing existing SBGR with Temporary Concrete Barrier (TCB) or installing asphalt curb in front of the existing SBGR to guard the surface runoff, and drain to the openings and outlet the surface runoff collection system (See Figure 4). Openings and outlets could be:

- Alternative 1
  Installing catch basins and drainage pipes to collect surface runoff and outlet to either existing stormwater management system or drain to the embankment with erosion control filled with free-draining material at the outlet. This alternative requires detail drainage design analysis.

- Alternative 2
  Constructing periodic drainage gaps along the TCBs or asphalt curbs to channel surface runoff to armoured drains (minimum 1m wide and 500mm deep) along the embankment slope and outlet to a sump. The armoured drains should be spaced at maximum 10m interval along the problem areas. The extent of the armoured drains depends on the Option selected. If Option 1 reconstruct the entire embankment is selected, then the armoured drains shall be extent to the toe of the slope with an outlet sump of 2m wide, 2m long and 500mm deep. If Option 2 reconstruct the granular zone is selected, then the armoured drains shall be extent to the bottom of the granular zone. All sumps (0.5m wide by 500mm deep) at the end of armoured drains shall be connected.

Rip-Rap R-10 grading aggregates are recommended to be used as free draining materials for armoured drains and erosion control. All Rip-Rap R-10 grading aggregates shall be placed using rock protection construction method from the bottom up (i.e. machine place and random manner and without geotextile separator). Refer to the following Ontario Provincial Standard Specifications for construction method and material selection:

- OPSS 511: Construction Specification for Rip Rap, Rock Protection and Gravel Sheeting
- OPSS 1004: Material Specification for Aggregates – Miscellaneous

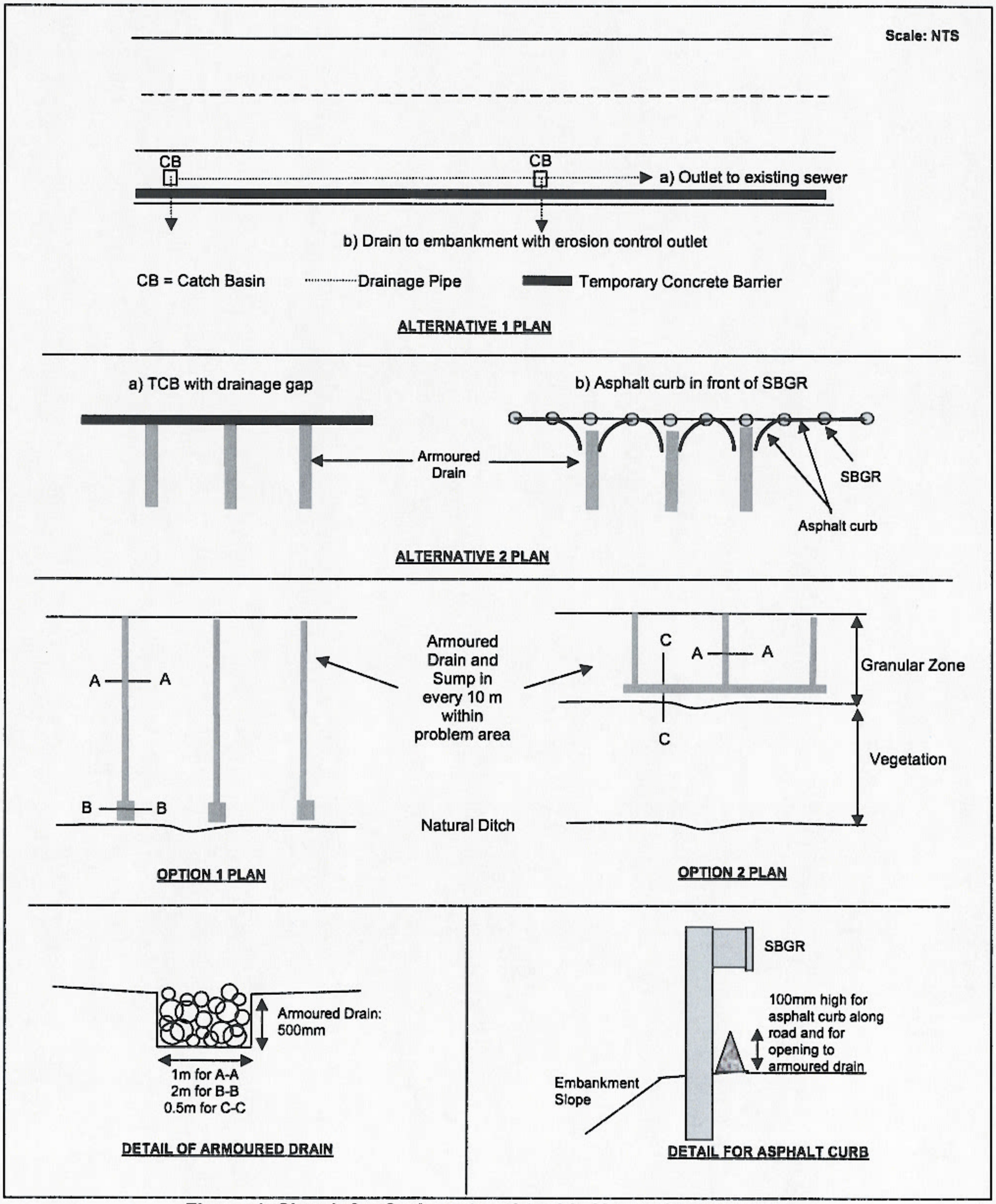

Figure 4: Sketch for Options 1 and 2 with Alternatives 1 and 2

The purpose of all three options is to increase the lateral support at the upper embankment slope by flattening or retaining/reinforcing the existing slope and to control surface runoff by collecting and out-letting surface runoff in a controlled manner.

It is recommended that CR select a preferred option on a risk-management basis.

However, based on the above discussion and consideration on advantages, disadvantage, traffic interruption, construction time and cost for each option, the prioritized options from a Foundations Engineering perspective are as follows:

Option 2:	*Re-grade only the upper portion of the embankment (granular zone) to a flatter slope*
Option 3:	*Install retaining soil system at the upper portion of the embankment (granular zone)*
Option 1	*Reconstruct entire embankment to permit flatter geometry at upper granular portion*

Option 2 would be more economical, would cause less traffic interruption and would required shorter construction time given that narrower the highway is acceptable. If narrower the highway is not acceptable, Option 3 would provide a viable solution with less risk but higher cost. Option 1 provides the least favoured option because it is the least economical option and it would disturb the stable vegetation slope area.

If you have any questions on this memorandum report for the W.O. 2012-11003 Remedial Measures for the Embankment Instabilities at Hwy 406 Northbound Approaching Westchester Avenue dated April 2, 2012, please do not hesitate to contact us.

Written by

LICENSED PROFESSIONAL ENGINEER
Y. T. F. LEUNG
100111889
April 2, 2012
PROVINCE OF ONTARIO

Fiona Leung, P. Eng.
Project Foundations Engineer

Reviewed by

LICENSED PROFESSIONAL ENGINEER
D. H. DUNDAS
12 04 02
PROVINCE OF ONTARIO

Dave Dundas, P. Eng.
Senior Foundations Engineer