LANDSLIDE RISK ASSESSMENT
SITE SUMMARY

Date: September 2006

1) **SITE:** **GP - 24**
Hwy 725:02 Hamelin Creek (BF-76987)

2) **REFERENCE LOCATION** along Highway:
Hwy 725:02 Km 17.22 at Hamelin Creek Crossing (BF 76987) Arch Culvert
The site location is shown in Figure 1.

3) **LEGAL DESCRIPTION:** SW05-81-5-W6M

4) **UTM COORDINATE:** N55.991618 E -119.216967

5) **AI FILE:**

BF-76987 bridge file records on slide failures and culvert deformation

6) **AI PLAN AND PROFILE:**

BF-76987 bridge file records on slide failures and culvert deformation

7) **GENERAL DESCRIPTION OF INSTABILITY**

At this crossing location, Hamelin Creek (flowing from west) confluences with a tributary (flowing from SW) at this highway crossing location. The site location plan is presented in Figure 1.

At construction of arch culvert in 2002/2003, slide movements (valley slopes and fill embankment slope) occurred. The arch culvert was constructed to replace two separate culverts which accommodated flows separately from Hamelin creek and its tributary. The slides caused structural deformation to the arch culvert. At post construction stage, continual settlement and lateral spreading movement of fill embankment is anticipated to require special maintenance efforts despite of geotechnical stabilization measures for the slides implemented to allow the grading construction to complete. The following details of site distress can be pertinent for the construction and post-construction stages.

7.1 CONSTRUCTION STAGE – SITE DISTRESS

In 2002/2003, an arch culvert of precast reinforcement concrete (r.c.) of 109.4m length was constructed under about 30m fill. The culvert was assembled with precast r.c. arch panels (@2.7m widths) to form a top arch of 5m radius with height of culvert arch of 6.2m (from bottom to top). The culvert bottom was constructed with a cast-in-place r.c. floor slab (1m thick and 10m wide).

From AIT records, the following river engineering design (BF 76987 drawings DD 1583 & DD 1583B) was constructed:

(i) Realignment of 2 creeks to relocate its confluence to an upstream new location. Previous to the channel realignment, the 2 watercourses were piped separately through 2 culverts with their inlets disposition at about 100m separations and with their outlets converge at the bottom of a V shape flow convergence pattern. The channel realignment for the new arch culvert pushed the new confluence upstream to form a T shape flow convergence pattern. The arch culvert was constructed along the stem portion of the T with newly created inflow channels along the top flanges of the T to require the flow to make a 90-degree turn to enter the culvert. Along the top flanges of the T, the newly created inflow channels on both sides of the inlet created erosion downcutting along the toes of the fill slope (40m-50m frontages) on each sides of the culvert inlet as a result of the designed channel lowering as mentioned in (ii) below.

(ii) A 5m lowering of channel gradeline was excavated at the new culvert inlet and upstream area of the channel realignment (i.e. at top of the new T shape flow pattern). The excavation lowering of channel gradeline incurred a subcutting of toes of valley slopes. The downstream area of new channel gradeline (at outlet of new arch culvert and at slightly upstream of previous confluence location of the 2 channels) was not changed.

Slide movements of valley slopes and the fill embankment occurred during culvert construction.

- Landsliding of valley slopes (NW and SE of culvert) occurred during the excavation and installation of culvert. The stockpiling of excavated soils along the slopes introduced a surcharge load to cause the landsliding; the lowering of channel gradeline also invoke a subcutting of toes of valley slope as partially contributory to slide failures. The stockpiling was later removed and relocated off the slope area.
- Landsliding of the fill embankment occurred shortly before it was constructed to grade (about 30m high fill). Frozen fill (with snow and ice) was investigated as the cause of failure. The various handlings, movements and lengthy duration of stockpiling of fills over a period of winter weather incurred the freezing of stockpile fill material.

The landsliding of valley slopes were stabilized with earth berming techniques and staging the culvert installation in sections with highway detours. It was later discovered that structural deformation cracking of the arch culvert (at wall and base) was at mid-section of the culvert length. It is apparent that the lateral forces from the valley slope slides has incurred structural deformation onto the arch culvert installation. Structural deformation of culvert occurs as a stress relief mechanism when the structural resistance of the structure is insufficient to resist the lateral forces of the landslides. Such structural deformation can be generated in stages:

- 1st stage deformation possibly occurred when the NW and SE valley slopes slided to act in a diagonal direction to deform the arch in a shear torsion manner during its erection stage when the valley slopes slided under the surcharge influence of soil stockpile loads.
- 2nd stage deformation possibly occurred when the frozen fill slided and needed subexcavation for its reconstruction. The subexcavation of frozen fill invoke a release of buttress and/or toe support of the previous NW and SE slides, thus reactivating lateral forces to act in a diagonal direction to further deform the arch culvert.
- For the future stage of maintenance, additional deformation can be likely as sliding movement of the upstream NW slope may be apparently possible because of the accelerated downcutting of channel towards upstream (as a result of 5m designed lowering of channel gradeline). It was observed that accelerated slumping and toe failures along upstream valley slopes have occurred as result of the designed lowering of channel gradeline. It can be likely that these toe failures may retrogress to activate large scale valley slope movements to generate lateral forces to act on the culvert especially at upstream inlet area. However, the magnitude of deformation may not be catastrophic and large as the existing fill embankment has been constructed to provide buttress effect.

A deformation survey of the structural damage was undertaken by a surveyor; however, the survey results were not definitive apparently due to bench marks located possibly within unstable grounds within the creek valley area.

The landsliding of "frozen" fill embankment was remediated with

(i) excavation replacement of top portion of "frozen" fill (to top of arch culvert); the bottom frozen fill (at culvert level) was left in-place as its replacement will likely damage the arch culvert to warrant total reconstruction

(ii) installation of "Stone Columns" at the bottom fill portion along both sides of the culvert structure with a portion of the frozen fill left in place

(iii) reconstruction of top portion of fill with a basal drainage blanket connecting to the stone columns.

The stone columns were installed around September 2003 and the top fill replacement was completed around end of 2003. The stabilization with "stone columns" provided a partial replacement of the incompetent "frozen" fill effecting soil improvement with an increase in shear strength and easy drainage medium for "frozen fill" along the sides of the arch culvert without causing damage (or total reconstruction) to the culvert structure installed. Such in-situ stabilization of "frozen incompetent soil" around the culvert provided a more stable toe platform to allow the top portion of the fill to be reconstructed.

The 2003 "stone column" stabilization provided substantial remediation to allow highway fill construction to be completed; however, future maintenance distress at this site is anticipated as a portion of "frozen" incompetent fill still remains in place at bottom of embankment. With time, the gradual melting and softening of the frozen material will invoke lateral spreading and settlement movement of the fill embankment to occur. Thus, a special level of pavement maintenance effort is anticipated necessary in response to future maintenance distress.

The reconstruction of fill provided toe buttress to substantially resist valley slope movements, thus lessening further lateral forces from further deforming the arch culvert structure at mid-portion of the culvert.

The history of this site was documented in a paper "Stabilization of a Highway Embankment Fill over an Arch Culvert using Stone Column" (R. Tweedie, R. Skirrow, et al. for 57th Canadian Geotech Conference in 2004). The landsides at this site was likely the result of design and construction oversights.

7.2 POST CONSTRUCTION - SITE DISTRESS (2005-2006)

From site observation, it can be noted that

- Settlement and lateral spreading of the fill is occurring.
- The vertical degradation along this frontage channels along the toes of fill is incurring slumping failures of toe fills and riprap protections along the bank at the culvert inlet area; the channel degradation and its upstream propagation also has incurred toe instabilities of natural valley slope both opposite and upstream of the inlet.
- At the downstream area, slumping of fill occurred at toe of fill embankment on the east side of the square box culvert outlet (without wingwall). A large slumping failure of north bank and a minor slumping failure of the south bank occurred along the downstream channel along a channel stretch 50m from culvert outlet. It is possible that, with filling-over of the old tributary channel, seepage flow of the old buried channel might be contributory to the slumping failure since the downstream banks were reconstructed from fills of channel realignment.

7.3 INSTRUMENTATION MONITORING

Since completion of the remediation (end of 2003), geotechnical instrumentation monitoring (by slope indicator and piezometer) indicated a substantial reduction of movement rates and lowering of pore pressures within the "frozen fill" zone still in-place. As per AIT records, the deformation survey of structure was not conclusive to indicate a definitive or a slowing-down rate of deformation (s.a. translational, rotational, cracking movements of the structure members) movement since previous survey benchmarks maybe located within the slide-active river valley area.

7.4 FUTURE MONITORING CONSIDERATIONS

Future instrumentation monitoring of the slope and deformation survey of culvert are considered required for maintenance evaluation of this site. As noted above that the site is only substantially stabilized, it is anticipated the future melting of frozen fill and weak soil conditions will incur some deformation of the fill embankment to include creep, lateral spreading movements and settlement. Due to the previous channel realignment causing continual undercut of slopes (both fill and valley), it is possible that future development of slope movements may manifest to further distress culvert and aggravate its existent deformation.

Due to the 5m-excavation lowering of channel gradeline, a proliferation of vertical degradation of channel towards upstream is anticipated possible to incur a relaxation of toe support along valley slopes upstream. This relaxation of toe support will potentially trigger movements of valley slopes (e.g. the NW slope) along the upstream stretch, in close vicinity of culvert, to exert lateral forces to cause additional distress to the culvert at the inlet area. In this regard, the NW valley slope may still be undergoing shear movement in relation to the SE slope at downstream end where the channel gradeline is considered not downcutting. The lateral forces probable from valley slope movements (from NW directions) may incur distress and deterioration of deformation of the culvert structure. Thus, the monitoring of valley slope movement as well as the deformation survey of the culvert performance should be carried out for the maintenance of the culvert infrastructure. The outcome of the deformation survey will provide future status of culvert structure integrity for planning of maintenance measure (s.a. repair of cracks of the arch culvert).

8) DATE OF INITIAL OBSERVATION:

2001 during construction of arch culvert

9) DATE OF LAST INSPECTION:

June, 2006 (Slidetour 2006)

10) INSTRUMENT INSTALLED:

At various stage of investigation in 2002-2003:
About 10-12 Sis
About 20 Piezo

11) INSTRUMENT OPERATIONAL:

3 SI
2 Piezo
Details of operational instruments remains to be clarified by Thurber.

12) RISK ASSESSMENT:

PF (9) * CF (4) = 36

- **PF = 9**
  - 2003 Remediation of valley slopes and fill embankment movement is considered substantially successful. The probability of catastrophic failure of fills to recur is considered low; distress movement of the fill is considered. However, for future assessment, it will be mandatory to continue instrumentation monitoring of this fill and to observe future deterioration of channel downcutting that may trigger slope movements. Special maintenance and repair are anticipated for toe stabilization works (s.a. riprap repair and toe berming in response to accelerated bank erosion).
  - However, future movement of the fills will comprise lateral spreading and settlement of fill. Such movements are anticipated to continue until dissipation of excess pore pressure (from frozen fill, ice and snow) stabilizes with time. As a trend of pore pressure dissipation has been monitored over previous 2 years after installation of the stone columns, a decreasing rate of lateral spreading is anticipated.
  - At the upstream banks and culvert inlet area, slumping of riprap protection occurred along the toes of fill slope on both sides of arch culvert inlet as a result of channel erosion. Future instability along the toe of the fill embankment is anticipated until the upstream channel gradeline stabilizes in the future.
  - At the downstream outlet area, fill slumping occurred at toe fill embankment and along vicinity banks:
    (i) Fill slumping at toe of fill embankment south corner of culvert (box) outlet.
    (ii) Slumping failure along north bank; minor slumping along south bank of creek.
    As this creek bank slope was possibly constructed of new fill on top of previous tributary channel, the failure maybe seepage related or remnant failures from past slides.

- **CF = 4**
  - At the present maintenance stage of this crossing structure, the possibility of movements of slopes that may catastrophically affect the precast r.c. arch culvert is considered low to medium.
  - Settlement of pavement (as a result of lateral movement and settlement of fill) will require continual maintenance effort until this partial "frozen fill embankment" stabilizes with time.
  - Other future concern will be accelerated channel downcutting and bank erosion that may develop
    (i) toe instability that can retrogress with time upslope to affect the fill embankment and highway. The potential for this hazard to affect the highway is considered low in 2006.
    (ii) erosion of Hamelin Creek banks may retrogress to trigger instability of valley slopes in vicinity area upstream. Such anticipated retrogressive valley slope movement may trigger deep seated soil movement of the valley slope (possibly NW slope) to possibly

exert lateral force onto the arch culvert to incur further deformation. It is advisable to monitor the stability of the valley slopes as well as undertake a deformation survey of the arch culvert.

(iii) Slumping of channel banks to require repairs of banks and riprap from time to time.

Note: This Risk Assessment rating is based on Scheme proposed by AI in the Request for Proposal. (2000)
Probability Factor (PF) : 1 to 20 scale
Consequence Factor (CF) : 1 to 10 scale

13) GEOTECHNICAL CONDITIONS

- The Hamelin Creek valley slope of the Peace Region area can be generally normally consolidated glacio-lacustrine deposits that can be sensitive to landsliding when subject to construction activities. During construction, the stockpiling of fill caused the sliding of valley slopes during the construction in 2001-2003.
- Future and maintenance concerns:
- The hydrotechnical design on a 5m excavation lowering of channel gradeline at the inlet area has triggered an acceleration of channel downcutting towards upstream. The accelerated channel downcutting is anticipated to cause vertical subcutting/erosion of toes of valley slopes to trigger future slope movements which may exert lateral forces to further deform the culvert.
- The realignment of channels to confluence from a previous Y confluence to an existing T confluence has effected bank erosion along upstream channel at the toes of the fills at the culvert inlet area. Future slumping along banks and their repair maintenance is anticipated. Retrogressive movements of toe slumping upslope will require monitoring.

14) CHRONOLOGY

- 2001-2003, Sliding of valley slopes and fill embankment occurred. The design and construction management of this bridge culvert crossing was undertaken by EXH Engineering Ltd (EXH)
- 2001-2002 the excavation (5m designed lowering of channel gradeline) and stockpiling of fill along valley slope caused slope movement failure.
  Distorting and deformation of culvert was observed due to the landsliding movement of the valley slopes. Thurber Engineering Ltd. (Thurber) was requested by EXH to investigate and remediate the failure.
- 2002, failure of 30m high embankment occurred due to "frozen fill" utilized in fill construction. Thurber again was requested by EXH to investigate and remediate and remediate the failure.
- 2003, remediation "frozen fill" slope was undertaken with
  reconstruction (fill replacement) of upper embankment above culvert structure
  installation of stone columns along sides of arch culvert to stabilize bottom of fill and
  "questionable soils along sides of arch culvert.
- 2003 Investigation of this slide, refer to a paper "Stabilization of a Highway Embankment Fill over an Arch Culvert using Stone Column" (R. Tweedie, R. Skirrow, etal for 57th Canadian Geotech Conference in 2004).
- 2006 Spring, Karl Engineering Consultants Ltd. (KARLENG) was retained by AIT as Regional Consultant Geotechnical Engineer to oversee this site in general as part of AIT's Risk Management of Landslide Sites.
- 2006 Spring, Thurber was separately retained by AIT as special geotechnical consultant to continue historic follow-up for this site of historic landslide distress. An instrumentation monitoring program will be undertaken as well.

- End