Appendix 'E'

Geotechnical Engineering

1.0 INTRODUCTION

The Belfountain dam is located on the west branch of the Credit River in the Belfountain Conservation Area in the town of Caledon. The Belfountain dam consists of a concrete / masonry overflow spillway structure with two sluices on the left bank. Right abutment of the dam and valley sides immediately downstream are steeply sloping with exposed bedrock in places. Left abutment (upstream and downstream) of the dam consists of a reinforced concrete retaining wall constructed with hand railing fixed to the top of the retaining wall. Beyond the left abutment retaining wall is a flat grassed public viewing area containing a fountain. The general layout of the Belfountain dam is shown on Figure 1.

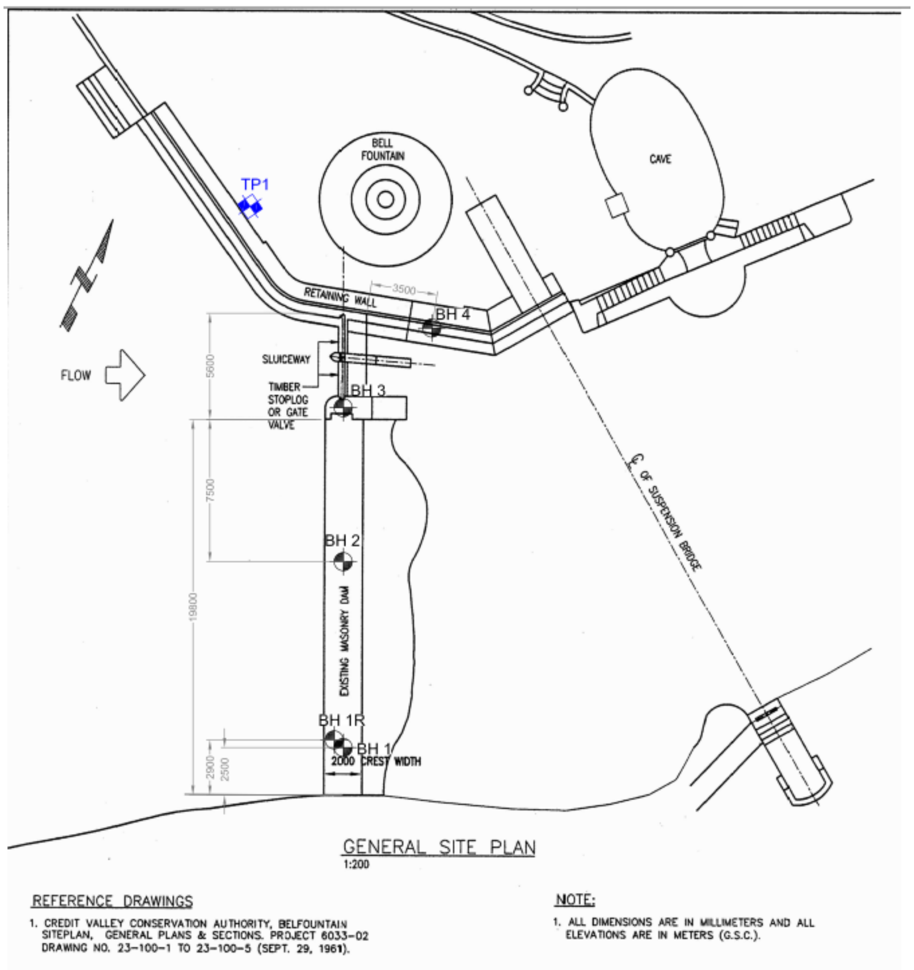

Figure 1: Belfountain Conservation Area Plan View (Extracted from Terraprobe, 2013)

Previous studies by Klohn Crippen Consultants and Terraprobe raised concerns on the stability of the left abutment retaining wall, specifically under design flood conditions. The lateral movement of the retaining wall is currently being monitored with an inclinometer which was installed by Terraprobe in 2013. Typical cross section of the retaining wall is shown on Figure 2.

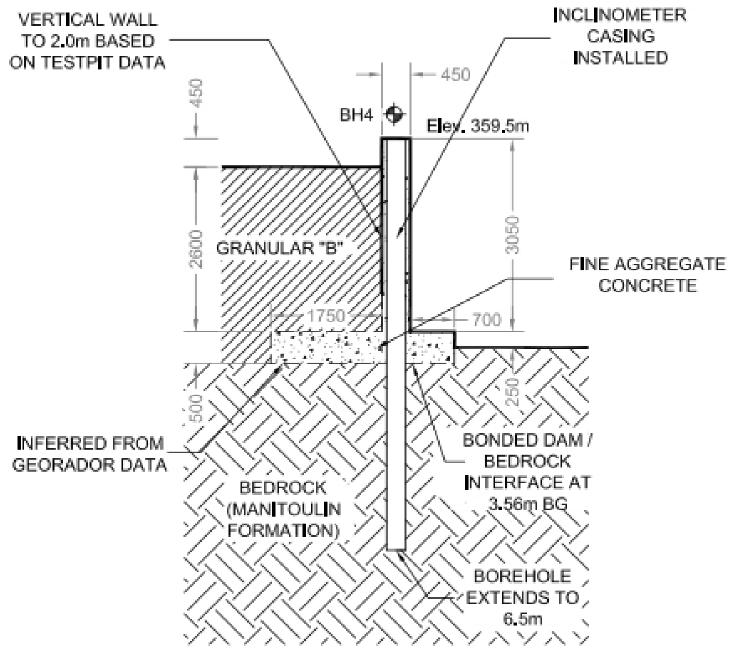

Figure 2: Typical Cross Section of the Retaining Wall (Extracted from Terraprobe, 2013)

The purpose of this study is to verify the stability of the retaining wall and assess remedial options to enhance the stability. The stability of the retaining wall is assessed for three scenarios: normal operating conditions, the design flood event and the design seismic event. Preliminary level design and analyses are then carried out considering three remedial options to improve the stability of the retaining wall.

2.0 RETAINING WALL STABILITY ANALYSIS

Stability analyses were performed for the three conditions outlined in the previous section. Only overturning and sliding modes of failure were checked in the analyses. The factor of safety criteria for these two modes of failure are summarized in Table 1. Bearing capacity and general loss of stability modes of failure were considered to be improbable due to the fact that the retaining wall is founded on bedrock. Liquefaction of the backfill soils together with the design flood was not considered in the analyses because the probability of a design seismic event occurring simultaneously with a design flood event, which would create the conditions necessary for liquefaction, is very low.

Table 1: Factor of Safety Criteria

Type of Analysis	Usual Loading	Design Flood Loading	Earthquake Loading
Sliding	1.5	1.1	1.1
Overturning	2.0	1.5	1.5

The three loading scenarios for which the analyses were performed and the associated assumed parameters are shown in Figure 3. The cross-section of the retaining wall reported by Terraprobe (2013) was used in the analyses. This cross-section was deemed to be the most critical for the stability of the retaining wall. The headwater and tail-water elevations for each of the three scenarios were obtained from the previous geotechnical investigation report (Terraprobe, 2013).

The results of the analyses are summarized in Table 2.

Table 2: Summary of Results for Retaining Wall Stability Analyses

Scenario	**Factor of Safety**	
	Sliding	**Overturning**
Normal conditions	2.6	8.2
Flood Conditions	0.7	1.9
Seismic Conditions	2.2	6.7

These stability analyses results indicate that the retaining wall does not meet stability requirements for the sliding mode of failure under the design flood loading condition. The main reasons for the lower factor of safety against sliding under design flood condition are:

- high lateral water pressure on the wall, and
- large uplift force at the base of the retaining wall which reduces the sliding resistance.

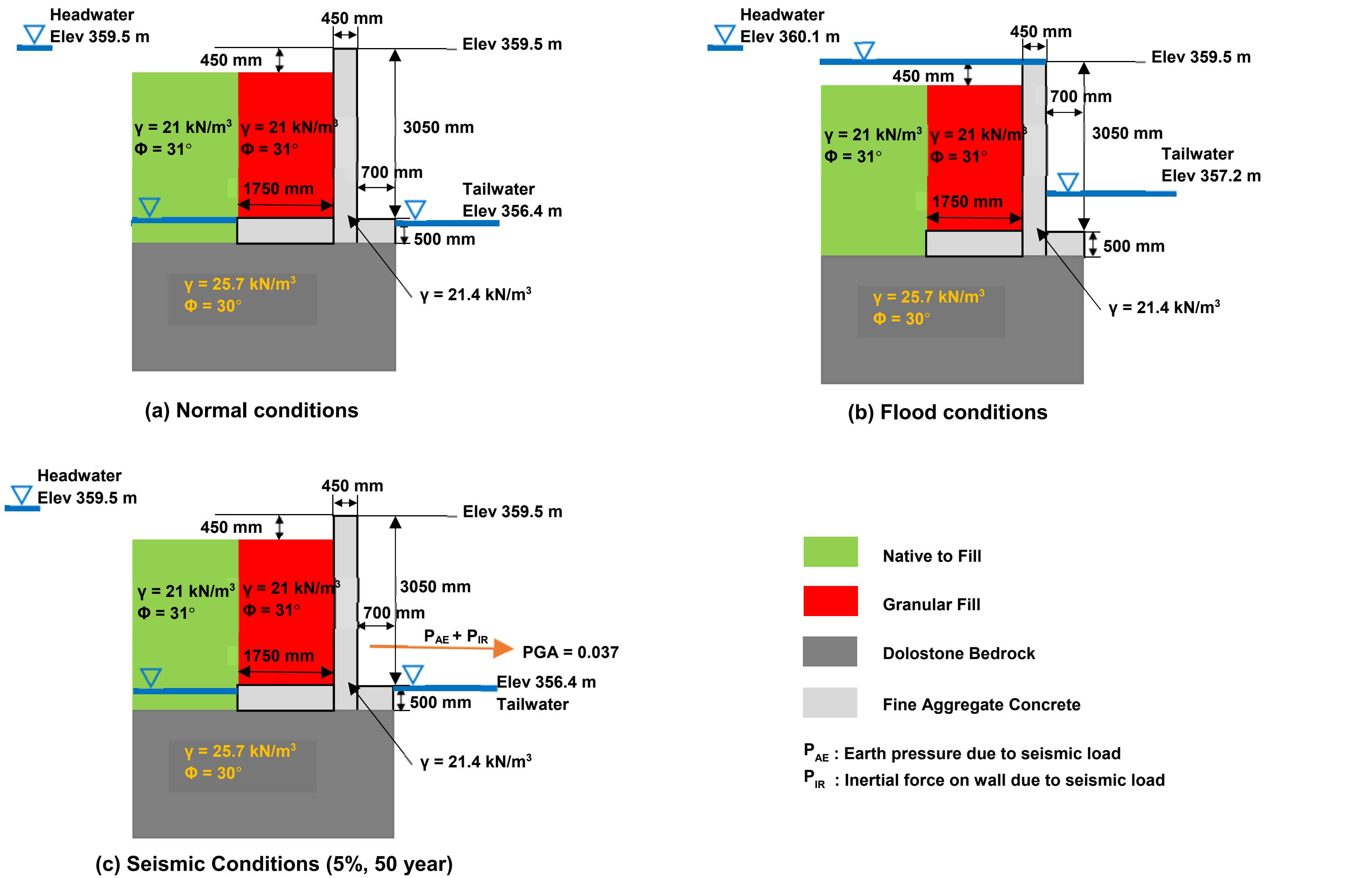

Figure 3: Stability Analysis

3.0 REMEDIAL OPTIONS

Three remedial options were considered to improve the stability of the retaining wall under the design flood conditions.

3.1 Option #1: Wall Drains and Pavement Layer

The first option is shown in Figure 4. It would include the placement of a pavement layer on top of the backfill soil all along the wall extending to some point behind the wall. This layer would help to keep the water level lower as it would reduce infiltration of water into the backfill soils. Drains would also be installed into the concrete retaining wall at some spacing on the tail-water side of the wall to drain any water that reaches the backfill soils.

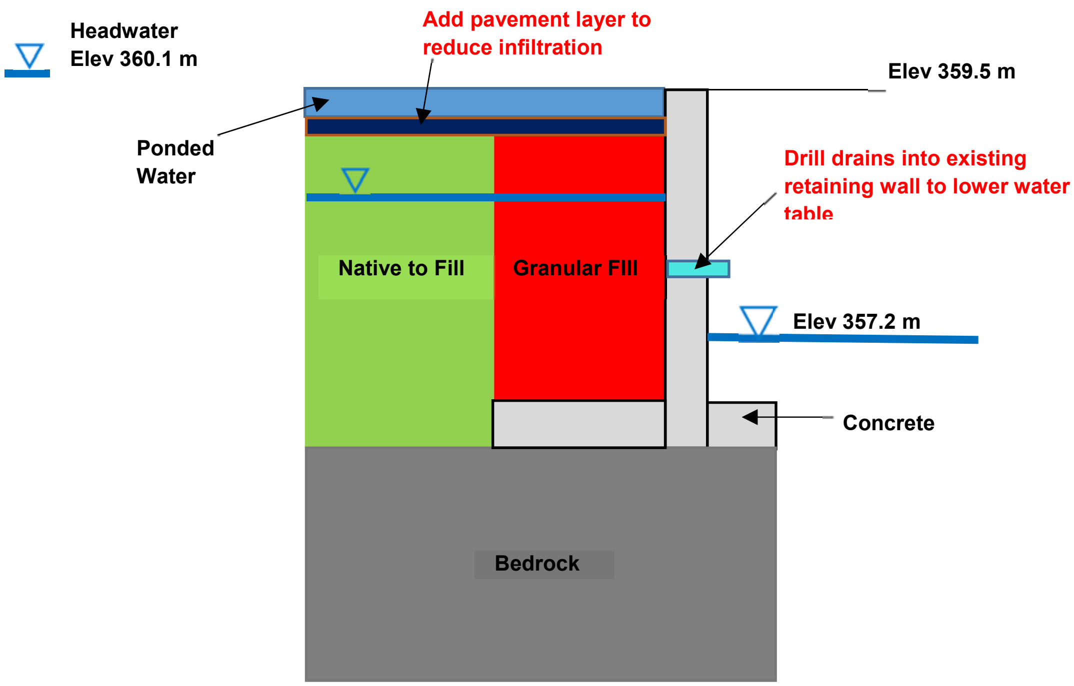

Figure 4: Remedial Option #1 (Flood Conditions)

Implementing these modifications would help lowering the water table behind the wall. The determination of the magnitude of drop in the water level requires seepage analysis. Although, based on the sliding stability analysis, it was determined that a hypothetical water level of 0.5 m below the backfill soils would provide an adequate factor of safety of 1.2 for the sliding stability under design flood condition.

The estimated remedial cost for this option would be in the order of $10,000.

3.2 Option #2: Perforated Pipe and Pavement Layer

The second remedial option is illustrated in Figure 5. It would include a perforated pipe installation at some location behind the retaining wall along the length of the wall which would outlet downstream of the wall on the tail-water side. A hole would need to be drilled somewhere along the wall on the tail-water side for the pipe outlet. A pavement layer similar to the one in the first option would also be included as part of this option.

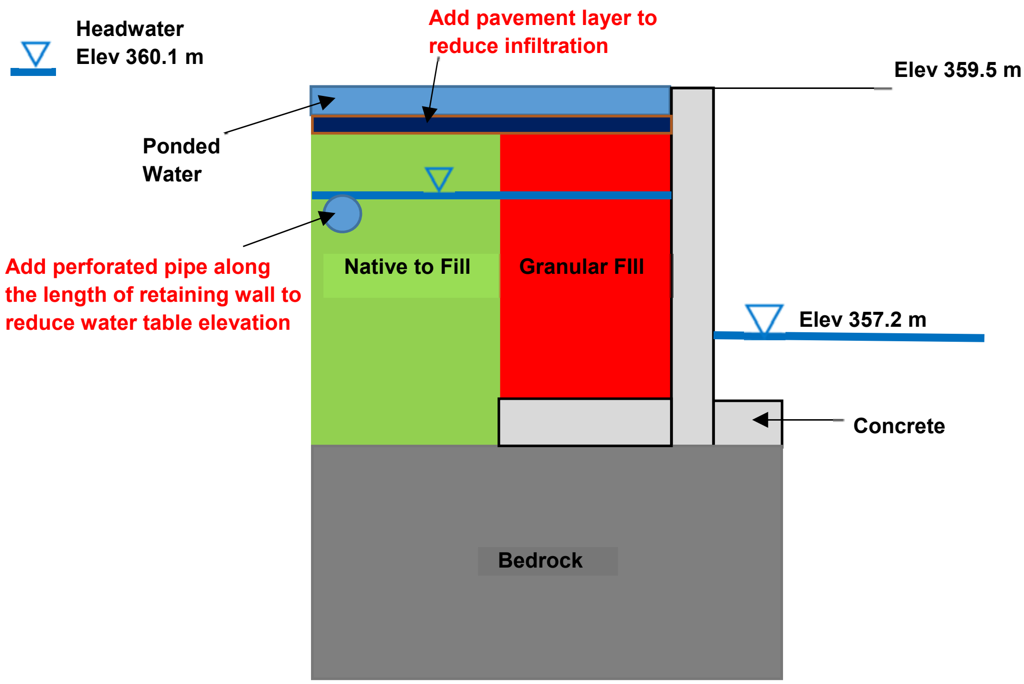

Figure 5: Remedial Option #2 (Flood Conditions)

Implementing these modifications would result in a decrease in the elevation of the water table behind the wall to the elevation of the perforated pipe. Since it was determined that a water level of 0.5 m below the backfill soils would provide an adequate sliding factor of safety of 1.2, the top of the pipe should be installed at 0.5 m below (or even lower) ground surface.

The estimated cost for this remedial option would be in the order of $15,000.

3.3 Option #3: Tie-backs

The third option is shown in Figure 6. It would consist of anchoring tie-backs to the wall at some spacing along the length of the wall and embedding them into the bedrock behind the wall. This would provide additional lateral support and increase the sliding resistance of the wall. This option would be cost prohibitive because of the major drilling activities that it would require and the tie-backs themselves in contrast to the two other options.

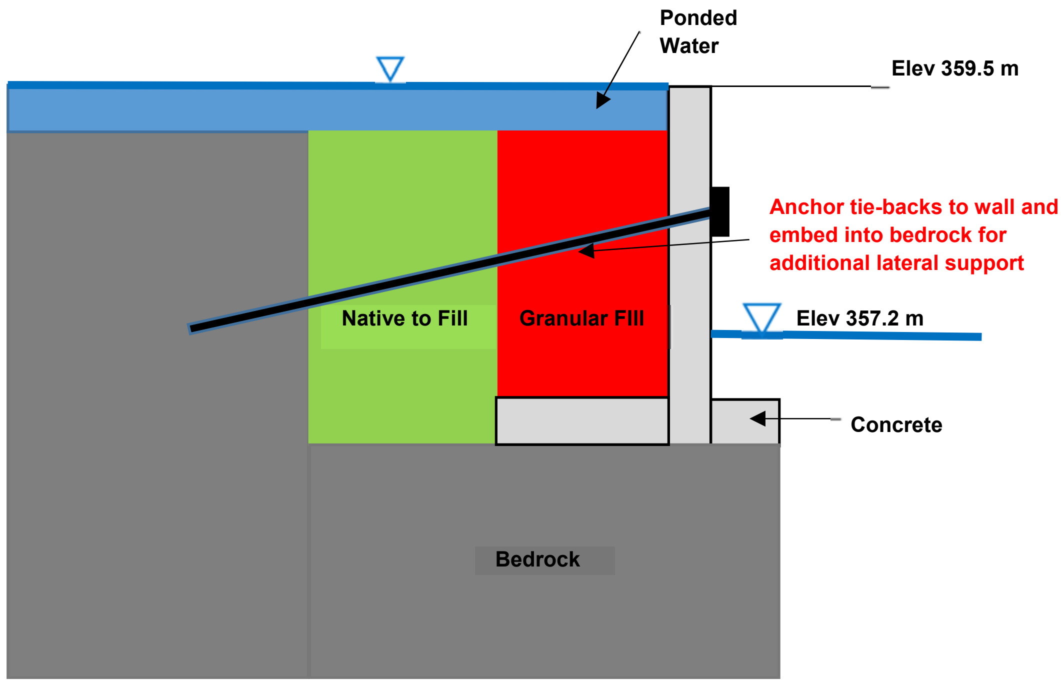

Figure 6: Remedial Option #3 (Flood Conditions)

4.0 RECOMMENDATIONS

A more detailed analysis of remedial option #1 is recommended to determine the following:

- the decrease in the elevation of the water table behind the retaining wall due to the proposed drains and pavement layer installations.
- the required size of the drains;
- the number of drains and the drain spacing along the retaining wall;
- the thickness of the pavement layer; and
- the extent of the pavement layer behind the retaining wall

5.0 REFERENCES

Terraprobe, 2013. Geotechnical Investigation and Dam Safety Report, Belfountain Conservation Area, Terraprobe Inc. May 2013.