Concentric Associates International Incorporated

LAKE GERALDINE DAM

DAM SAFETY REVIEW

DECEMBER 11, 2006

PRODUCED FOR:

THE CITY OF IQALUIT

PRODUCED BY:

CONCENTRIC ASSOCIATES INTERNATIONAL INCORPORATED

CONCENTRIC PROJECT REFERENCE NUMBER:

06-1429

Lake Geraldine Dam
Dam Safety Review

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EXECUTIVE SUMMARY

The City Of Iqaluit retained Concentric Associates International Incorporated (Concentric), in September 2006, to prepare a Dam Safety Review (DSR) for the Lake Geraldine Dam.

The DSR was conducted during the period October through December 2006, in accordance with the Dam Safety Guidelines, (*DSG January 1999*) prepared by the Canadian Dam Association.

As a result of the DSR, the following conclusions and recommendations have been made regarding Lake Geraldine Dam:

1. This DSR is incomplete due to design documentation requested, but not provided by the design engineer, see below.

2. In accordance with Section 1 of the DSG, the dam continues to operate under a High Consequence Category.

3. Raising of the earth embankments and concrete gravity dam section was completed in 2006. The design review for the new dam structure has been limited to visual information obtained on site and incomplete design documentation provided by the design engineer Trow Associates (Trow). Design calculations, material testing reports and site reports do not appear to be on record with the city, and were requested of, but not provided by, Trow. These documents should be kept in the permanent file and provided to complete this, and subsequent, Dam Safety Reviews.

4. Rock Anchors were added in 2005. Based on the limited information provided, we were not able to confirm with certainty if the rock anchors were sufficiently pretension to resist over stressing of the rock foundation at the new reservoir level under ice loading conditions.

5. No permanent instrumentation was added during the 2006 dam raising. The monitoring and instrumentation of the dam does not appear to meet the recommendations of the DSG

6. As per the previous DSG, the dam is still in non-compliance with the requirements of Sections 3 and 4 of the DSG. The following documents do not exist at this time:
   - Permanent File
   - OMS Manual
   - Logbook
   - Emergency Preparedness Plan

5. A Dam Safety Inspection (DSI) should be conducted in 2007. This is essentially a yearly non-invasive review comprising a visual inspection to identify any changes in condition, or any observed concerns. The DSI conducted in 2006 identified leakage through the spillway which requires follow-up in 2007.

6. An underwater inspection of the submerged structures should be done in 2007. This inspection should be coordinated with, and be under the direction of, the DSI recommended in Item 5, above.

7. A future DSR should be scheduled for no later than 2013.

1. INTRODUCTION & SCOPE OF WORK

Significant modifications to the Lake Geraldine Dam in 2005 and 2006 triggered the requirement for a Dam Safety Review (DSR), in accordance with the Canadian Dam Association publication, Dam Safety Guidelines (DSG), published in January 1999.

The DSG applies to those structures that are at least 2.5 meters in height, and which have at least 30,000 cubic meters of storage capacity. The Lake Geraldine Dam exceeds these minimums.

The DSG document is far reaching in terms of applicability and requirements for conformance. This is understandable as the type and complexity of structures that fall under the jurisdiction of the document varies considerably, from relatively small and simple embankments or dikes to massive and complex dams associated with hydroelectric generating facilities, irrigation, flood control, etc.

The DSG requires that all structures exceeding the height and volume minimums described above be classified according to their "consequence category", that is, the consequence of dam failure in terms of life safety, and socio-economic impact. The category assigned may range from very low to very high. The consequence category dictates the requirement and frequency of Dam Safety Reviews.

A Dam Safety Review (DSR) is a comprehensive, formal review process, conducted at regular intervals, that involves completion of checklist items in accordance with the Dam Safety Guidelines. The DSR forms a baseline of dam history, condition, repair requirements, and extensive documentation of monitoring, operating, safety and emergency procedures.

The frequency of DSR's varies depending on consequence category. For structures where significant life safety and/or socio-economic consequence exist, the DSR is usually conducted every five (5) to ten (10) years. In the case of the Lake Geraldine Dam, the required interval is seven (7) years.

It is required in the DSG document that in the interval between DSR's, a Dam Safety Inspection (DSI) would be performed on an annual basis. The DSI is a much less comprehensive review, comprising a visual inspection to identify any changes in condition, or any observed concerns. The results of the DSI are incorporated into the DSR documentation. A DSI may trigger repairs, or changes in standard operating procedures.

Under the current DSG, a DSR was required for the Lake Geraldine Dam due to the "major modification to the original design or design criteria" represented by the raising and reinforcing program undertaken over the summer of 2006

The level of detail required to conduct a DSR is influenced by several factors as follows:

- Importance of structure
- Complexity of structure
- Consequences of failure
- Completeness, continuity, and availability of record documentation

- Current condition

A summary of the methodology to complete the work is presented below:

1. Acquisition and assembly of chronological documentation, including but not limited to:

    - Design Documents
    - Repair Specifications
    - Past Condition Assessment Reports
    - Records of Alteration

2. Review of all available record documentation.

3. Perform a site inspection to assess the current condition of the structures. No invasive work was performed; the condition assessment was visual in nature. Invasive assessment was not believed necessary given the amount of record documentation available.

4. Interview maintenance and management personnel as required and appropriate.

5. Execute the DSR checklist of items.

6. Prepare the draft DSR report, complete with site surveys, photographs, structural sections, field notes, discussions and recommendations as required and appropriate. Submission to and discussion with the City Engineer.

7. Submit the final DSR report.

2. HISTORY & BACKGROUND

In the following chronological summary, record documents have been referenced. After each reference, a number appears in parenthesis. That number corresponds to tabulated record document numbers in Section 4, where details are provided on the document source.

2.1 Reservoir

The City of Iqaluit derives its water supply from Lake Geraldine, which is retained by a structure consisting of a cast in place concrete gravity dam incorporating a spillway section and a cast in place concrete cut-off wall and embankment. All concrete structures are believed to be founded on rock, and engage rock at their abutments.

Lake Geraldine is a natural body of water in an irregularly shaped basin. It is fed by rainfall and snow/ice melt from a watershed with an area of approximately 385 hectares.

2.2 History

In the late 1950's, the demand for a reliable year round source of water resulted in the construction of a cast in place concrete gravity dam, and a section of earth berm with a central cast in place concrete cut off wall. The project was designed and built by the Department Of National Defense. According to the literature, the original construction took place circa 1958.

Since that time, as the City has grown and water demands have risen, the dam has been raised four times to increase the storage capacity.

The first height increase of 0.3m reportedly took place in 1979. This involved a concrete extension, which was dowelled into the existing structure.

The second construction took place in 1985, and increased the height of the spillway structure by approximately 1.15m. The embankment portion was widened and heightened as well to accommodate the increased storage capacity. Again, the extension was constructed of concrete dowelled into the existing structure, and incorporated a steel formwork frame over the spillway section.

The third extension was done in 1995, and increased the height of the gravity dam structure by a further 1.5m of concrete, with a corresponding increase in berm geometry. Based on analysis done prior to the extension, it was determined that the gravity dam would not have an adequate factor of safety against overturning if the extension was simply "dowelled-in" as before. The 1995 alteration therefore included an extensive rock-anchoring program for the gravity dam portion to provide the required stability to the structure.

The latest extension was completed in two phases over 2005/06. Additional rock anchors were installed thought the gravity dam in 2005 in preparation for a further height extension of 2m in 2006. The existing embankments were enlarged and the existing cut-of-walls were extended in height. A new embankment and cut off wall were installed to the south of the existing dam structures.

In the time span of the available historical data, which extends back to 1984, there have been only a few notable events relating to the safety and serviceability of the dam structures.

- In November 1984 joint and patch repairs were made to localized areas on the upstream side of the spillway structure by diving contractors. Reporting was minimal.
- In June 1990 an inspection report (3) of the structure by diving contractors was made following construction blasting. The 1984 repair areas were also assessed. The 1984 repairs were noted to have generally deteriorated. No conclusions were made. Reporting was minimal.
- In June 1990 a visual inspection report (4) was prepared for the City by an engineering consultant, as a result of the construction blast. No significant damage was noted, and no recommendations were made for repair.
- In July 1990 a dam inspection and stability report (5,6) was conducted for the City by an engineering consultant. Recommendations were made regarding repair of leaking joints, and provisions to increase stability should the dam be raised in the future.
- In September 1990, a diving contractor performed crack repairs and prepared an inspection report (7). Repair material used was oakum. These repairs appeared to generally address areas observed in the June 1990 diving inspection. Reporting was minimal.
- In October 1997 a visual inspection report (10) was prepared for the City by an engineering consultant. Leaking cracks were identified, however, these were not viewed as being structurally significant. It was recommended that leaking cracks be chemically grouted. This work was not done.
- In June 1998, a study (11) was prepared for the Department Of Public Works by an engineering consultant to assess the hydrological impact of a dam failure on a proposed downstream hospital site.
- A diving inspection was reportedly carried out in 1999. A report was not submitted. A video record was provided. The video provides images of the water intake, but no record of the condition of the dam.
- A previous DSR (the first on record) was conducted in 2001

- DSI's were conducted in 2004 and 2006. The 2006 DSI was done in conjunction with this report.

2.3 Description of Structure

The dam is comprised of a concrete section (incorporating a concrete spillway) and earth embankments to the north and south. The 15.3m wide spillway has an upper elevation of 111.33m (the new operating level of the reservoir) while the concrete sections on either side of the spillway have an elevation of 112.28 m. At the operating level of the reservoir, the dam has approximately 0.95 m of freeboard. The southern section of the concrete dam extends approximately 39.1 m to the south rock abutment. The northern section of the concrete dam extends 13.3 m to the north of the spillway section, where it joins the earth embankment. The central and northern earth embankments extend approximately 135 m to the north rock abutment. A new earth embankment (approximately 68.5m long) was installed in a valley to the south of the existing structures in 2006. The embankment sections of the dam incorporate a concrete cutoff which is reportedly founded in rock and has an upper elevation of 112.30 m (approximately 0.97m of freeboard). The concrete section of the dam is also reportedly founded in rock.

2.4 Relevant Record Documents

The following documentation has been utilized in the preparation of this report. Other record documentation was provided but not directly applicable to the DSR.

TABLE I
RELEVANT RECORD DOCUMENTATION
LAKE GERALDINE DAM

No.	Date	Description	Author
1	December 1957	Water Storage Dam at Lake Geraldine (3 Drawings)	DND
2	August 1984	Lake Geraldine Water Supply Report	OMM
3	January 1985	Water Supply Improvement Report	OMM
4	June 1990	General Diving Report	Arctic Divers
5	June 1990	Dam Inspection for Blast Damage	Hardy BBT
6	July 1990	Dam Inspection & Leakage Repair	Acres
7	July 1990	Dam Stability	Acres
8	Sept. 1990	Diving Report	Arctic Divers
9	Feb. 1995	Lake Geraldine Storage Report	OMM
10	June 1995	Lake Geraldine Storage Design Dwgs. & Specifications	OMM
11	October 1997	Dam Inspection	Trow
12	June 1998	Dam Failure Study	EBA

13	March 2002	Dam Safety Review	Trow
14	August 2003	Lake Geraldine Dam Repairs 2003	Dillon
15	February 2005	Dam Safety Inspection	Concentric
16	March 2005	Geotechnical Investigation	Trow
17	May 2005	Lake Geraldine Dam Rock Anchors 2005 (Specifications and 4 Drawings)	Trow
18	February 2006	Lake Geraldine Dam Earth and Concrete Work 2006 (Specifications and 11 Drawings)	Trow

3. COMMENTARY ON DAM SAFETY REVIEW REQUIREMENTS

According to the Dam Safety Guidelines, the document applies to those structures that are at least 2.5 meters in height, and which have at least 30,000 cubic meters of storage capacity. The Lake Geraldine Dam exceeds these minimums.

The Dam Safety Guidelines document is far reaching in terms of applicability and requirements for conformance. This is understandable as the type and complexity of structures that fall under the jurisdiction of the document varies considerably, from relatively small and simple embankments or dikes to massive and complex dams associated with hydroelectric generating facilities, irrigation, flood control, etc.

The document requires a systematic checklist review, which includes the following items. For each item, the applicable Section number from the Dam Safety Guidelines is shown in parenthesis.

1. Dam Classification (1)
2. Site Inspection (2)
3. Design & Construction Review: (2)
   - 3.1. Earthquakes (5)
   - 3.2. Floods (6)
   - 3.3. Discharge Facilities (7)
   - 3.4. Geotechnical Considerations (8)
   - 3.5. Concrete Structures (9)
   - 3.6. Reservoir & Environment (10)
   - 3.7. Construction (11)
4. Operation & Testing (2,3)
5. Maintenance (2,3)
6. Surveillance & Monitoring (2,3)
7. Emergency Preparedness (2,4)
8. Compliance With Previous Reviews (2)

3 LAKE GERALDINE DAM DSR

Dam Classification (DSG Section 1)

Based on the Dam Safety Guidelines, and the dam structure itself, the Lake Geraldine Dam has a consequence category of "High" for both the *Life Safety* and *Socioeconomic, Financial and Environmental* categories. The "High" classification is assigned by the DSG, in the case of life safety, if loss of life would likely occur as a result of dam failure. A "High" category is assigned in the socioeconomic category if, in the event of a dam failure, the cost to the community in terms of social and financial impact would be significant. Under the guidelines it is required to have a Dam Safety Review every seven (7) years for those structures with a high consequence category.

Site Inspection (DSG Section 2)

A visual site inspection of the dam structures was performed in October 2006. The inspection was non-invasive in nature, and did not include an underwater assessment.

A summary of observed conditions is as follows:

- The visible portions of the concrete structures are generally in good condition.
- There was no evidence of distress or overstressing of any portion of the visible concrete structures.
- The north and central embankments appeared to be in a stable condition. Slopes of 2H:1V appeared to be maintained on the down stream rip-rap and in the up stream rock fill.
- There was a slight rise in the reservoir level however most of the extension had not been impacted.
- The reservoir level had yet to have an impact on the south embankment.
- A leak was noted in the spillway portion of the dam; this leak was estimated at perhaps 30-40 litres per minute. This leak should be re-assessed in the spring of 2007 in conjunction with the 2007 DSI and appropriate measures taken.

Design & Construction Review (DSG Section 2)

This section constitutes the bulk of the Dam Safety Review process. The intent is to determine if the existing dam configuration satisfies performance criteria given in the DSG for safety and serviceability, in response to likely loads impinging on the structure. We have followed the format in the DSG document for convenience and clarity.

Earthquakes (DSG Section 5)

According to the DSG, dams shall be evaluated to withstand a Maximum Design Earthquake (MDE) without release of the reservoir. For a High Consequence Category, the DSG requires evaluation at 50% - 100% of the Maximum Credible Earthquake (MCE). To paraphrase the DSG, the MCE is defined as the largest reasonably conceivable earthquake that appears possible under the presently known tectonic framework.

Concrete Gravity Dam Portion

For the concrete portions of the dam, two sections were assessed; the spillway section and the gravity dam itself. For each section, the worst case was assessed, which corresponded to the maximum retained height, that is, the maximum distance from the lake bottom at the base of the dam, to the crest of the dam. As the lake bottom tends to undulate, the retained height varies to some degree.

The MDE loads were applied in combination with other loads in accordance with Section 9.4 of the DSG, Load Combinations, Concrete Structures.

In the load combination case involving the MDE, the overall contribution of seismic loads is less than 10%, and is not considered significant compared to uplift and hydrostatic forces, and therefore does not govern the performance of the structure.

Embankment Dam Portion

The configuration of the embankment portion of the dam has been substantially modified. At present the available information is considered to be too limited to perform a comprehensive review. Once sufficient design and construction documentation becomes available this section can be finalized. In the continuing absence of such documentation independent material testing and design analysis will have to be performed to complete this section of the DSR.

Floods (DSG Section 6)

According to the DSG, dams shall be evaluated to safely pass an Inflow Design Flood (IDF), which is based on Consequence Category and the Probable Maximum Flood (PMF). The PMF is an estimate of the most severe "reasonably possible" flood at a particular location and time of year. For a High Consequence Category, the DSG requires an IDF with an Annual Exceedence Probability (AEP) of between 1/1000 and the PMF.

The contributory area for the reservoir is essentially the water shed of the Sylvia Grinnel River. As the 2006 dam raising has not intersected additional drainage areas we deem the inflow characteristics on the reservoir and dam structure to be unchanged. The spillway characteristics (freeboard and width) have also been maintained with the new dam structure. As climate data has not indicated a significant change in rain and snow events, the statistical flood analysis carried out with the 2001 DSR is considered to be still valid and the dam is considered to safely meet the requirements of the DSG.

Discharge Facilities (DSG Section 7)

Section 7 of the DSG has a broad applicability that includes flow control equipment, instrumentation, and emergency backup equipment, which are relevant to more complex structures. In the case of the Lake Geraldine Dam, the applicability only involves the spillway section.

As per the previous section significant changes have not been made or occurred with respect to the freeboard of the dam and the Inflow Design Flood. Other factors affecting the discharge facilities such as wave height (related to the fetch of the lake) and the accumulation of floating debris have also not changed significantly. We therefore consider the analysis of the previous DSR to be valid. The dam structure therefore meets the requirements of the DSG.

Geotechnical Considerations (DSG Section 8)

Section 8 of the DSG presents Geotechnical considerations for proposed dams, as well as for several configurations of existing dams.

Concrete Gravity Dam Portion

For dams on rock foundations the DSG indicates that geotechnical investigations and design should be sufficient to ensure that *foundation stability*, *shear strength parameters* and *seepage and drainage* issues are identified and addressed.

The March 2005 Geotechnical Investigation indicates that two boreholes were drilled in the vicinity of the gravity dam. The bedrock in this area is categorized as gneiss: with a quality range of very poor to excellent; an allowable bearing pressure in excess of 480 kPa; and an (estimated minimum) residual angle of friction of 23 degrees. Parameters for the use of rock anchors in the design of the dam are also stated in the March 2005 Geotechnical Investigation.

Information indicates that a peak angle of internal friction of 40 degrees has been used with respect to design of the gravity portion of the dam against sliding. The March 2005 report explicitly states that a residual angle of internal friction of 23 degrees should be used with respect to resistance to sliding.

Our review of the present dam configuration indicates that *seepage and drainage* are not presently areas of concern. *Shear strength parameters* are such that rock anchors are required to act in shear at the rock/dam interface. A review of the structural drawings would indicate that the listed factors of safety against sliding do not utilise the geotechnical recommendations. Our review of the installation requirements for the rock anchors could not confirm with certainty that the *foundation stability* was adequate at the operating level of the reservoir under the listed ice load conditions.

Embankment Dam Portion

The DSG groups embankment dams and dams on soil foundations into the same general category. Seven sub-categories are listed for embankment dams: *monitoring and instrumentation*; *stability and deformation*; *seepage and drainage*; *cracking*; *surface erosion*; *liquefaction*; and *earthquake resistance*.

The raising of the reservoir has entailed increasing the height of the central, north and installation of a new south berm. The general construction methodology has been to leave the existing berm structures in place, extend the height of the existing cutoff wall and install the new structures over the existing berm materials. The cutoff wall for the new south berm has also been extended into rock while the new berm is founded on the native overburden. Cutoffs are installed to reduce seepage and uplift in the down stream embankment structure and add little in the way of extra stability. It is generally accepted that, where suitable soils are available, and earth core will be safer and more durable than concrete. The concrete cutoff is deemed to be a necessity of cost and the scarcity of appropriate materials.

8.2.1 Monitoring and instrumentation:

Given the available documentation, a consistent monitoring program does not appear to exist and no active instrumentation equipment has been installed. Engineering inspection reports are limited to those listed in table 1 and any record of city staff performing regular monitoring is not available. The current monitoring and instrumentation program is deemed to not meet the requirements of the DSG.

8.2.2 Stability and deformations:

The configuration of the embankment portion of the dam has been substantially modified. At present the available information is considered to be too limited to perform a comprehensive review. Once sufficient design and construction documentation becomes available this section can be finalized. In the continuing absence of such documentation independent material testing and design analysis will have to be performed to complete this section of the DSR.

8.2.3 Seepage and Drainage:

Seepage is controlled by the concrete cutoff wall; however, no consideration has been made for the monitoring of hydraulic gradients across the embankment. As stated above, concrete cutoffs are less safe and less durable than a properly designed earth core. Steady state seepage is more constant in an earth core dam and will not be significantly impacted by movement and shifting materials. Filter and drainage requirements become less critical for a concrete cutoff wall, however, continual monitoring of the hydraulic gradient becomes more important. Installation of piezometers in the down stream embankment would allow monitoring of the operational pore-water pressure and infer the condition of the concrete cutoff wall. Information would be used to: verify seepage rates through the embankment; verify slope stability calculations; and locate problem areas along the length of the dam. It was identified in the geotechnical investigation that, within the north berm, a section of the original cutoff wall was not founded in rock. Although we can infer that the dam has performed adequately regardless of this condition, the raising of the reservoir would effectively increase: the head of water on the upstream face of the cutoff; the seepage rates across the breach; and the piping and uplift forces acting on the downstream embankment structure. Although the geotechnical investigation recommended that this section of the cutoff be grouted to rock, we have no record of this repair taking place. Given the assumption that the concrete cutoff wall is intact and founded in rock, we deem the requirements of the DSG to be met. However this assumption would be confirmed through the installation of proper instrumentation in accordance with section 8.2.1 of the DSG.

8.2.4 Cracking:

Cracking is typically more relevant to earth core dams. Given the rock facing and the concrete cutoff, the current configuration of the dam is deemed to meet the requirements of the DSG.

8.2.5 Surface Erosion:

Both upstream and downstream embankment slopes are faced in rock. The requirements of the DSG are therefore deemed to be met.

8.2.6 Liquefaction:

No materials identified in the geotechnical investigation appear to be susceptible to liquefaction. The requirements of the DSG are therefore deemed to be met.

8.2.7 Earthquake Resistance:

At present, the available information is considered to be too limited to perform a comprehensive review. Once sufficient design and construction documentation becomes available this section can be finalized. In the continuing absence of such documentation independent material testing and design analysis will have to be performed to complete this section of the DSR.

Concrete Structures (DSG Section 9)

Where the embankment structures predominantly fall under Section 8.2 of the DSG, Section 9 outlines the requirements for concrete structures. The DSG reviews the performance of concrete structures by the following sub-categories: *General*; *Condition of Structures and Sites*; *Loads*; *Load Combinations*; *Design Analysis*; *Performance Indicators*; and *Acceptance Criteria*.

In being provided with the tender drawings and specifications, we deem there to be sufficient documentation to complete a basic review of the design. However, certain concerns have been raised and will have to be addressed in a more comprehensive review of the design. This review cannot be completed without further information being supplied by the design engineer (Trow). Without independent confirmation of these deficiencies, the dam does not meet the requirements of the DSG.

9.2 Condition of Structures and Site:

The structure was visually inspected on site. At the time of our visit, we did not observe any conditions that would adversely affect the structural adequacy and/or performance. The concrete structure is generally considered to be new with no deficiencies noted.

9.3 Loads:

The loads under consideration are listed as follows:

- Dead loads (D).
- Normal headwater level (H).
- Headwater level due to Inflow Design Flood (H_F).
- Internal water pressure and foundation uplift forces (U).
- Static and dynamic thrust created by an ice sheet (I).

Loads associated with the Maximum Design Earthquake (Q) are not listed on the drawings. Rock anchors are not listed in the DSG (herein denoted as R). Silt and back fill loads (S) are not deemed to be an issue given the past history and construction of the dam. Temperature loads (T) are generally not considered for gravity dams.

9.4 Load combinations:

Of the load combinations listed in the DSG the three which are most relevant to the dam raising are:

9.4.1 Usual Loading: D+H+I+U+R

9.4.3 Flood Loading: D+H_F+U+R

9.4.4 Earthquake Loading: D+H+Q+U+R

9.5 Design and Analysis:

The DSG allows for the load combinations listed in section 9.4 to qualify to be treated as static load cases. Under the assumption that Ice has no (or little) impact on the flood and earthquake loading cases, the usual loading case governs. Given the prescribed loading, the dam must be designed to resist and prevent:

- Sliding at the dam/foundation interface, within the dam and at any plane in the foundation.

- Overturning
- Overstressing of the concrete dam or foundation
- Excessive seepage through the foundation or joints in the concrete dam.

Given the above, we undertook a rigid body analysis of the dam structure utilising 2 dimensional models of the dam at select locations. In general, our analysis revealed the following:

- The loads listed on the structural drawings appear to be realistic.
- The original rock anchors (1995) do not appear to have been utilised in the resistance calculations.
- The free body diagrams indicated on the drawings appear to represent the worst case (highest head) for both the spillway and the typical gravity dam sections.
- Discrepancies between the angle of internal friction used on the drawings and the recommended value indicated in the Geotechnical Investigation report friction remain unexplained.
- To accurately determine the factor of safety against sliding (sliding factor), the angle of internal friction, angle of sliding friction (or coefficient of friction) and estimate-able anchor tensions would have to be known. Given the information provided, the lowest limit on the sliding factor would be approximately 1.6.
- Provided the full service load of the rock anchors is mobilised, analysing the dam at the critical sections indicated that the minimum factor of safety against overturning is approximately 1.5
- Pressures at the toe of the dam are highly dependant on the tension in the rock anchors. Without additional information (regarding the installation and pre loading of the rock anchors) it is possible that allowable pressures are exceeded at the operating level of the reservoir under ice load condition (the usual load case).
- Negative pressures are indicated in the heel of the dam.
- Seepage is not currently considered to be an issue.

9.6 Performance Indicators:

The DSG recommends that the assessment of concrete dams include the following performance indicators:

- Position of resultant force
- Normal stresses at the heel and toe

- Average shear stresses acting on the surface
- Sliding factors
- Observed conditions of the structure and site

Position of resultant force: Analysis using service load limits for rock anchors indicates that the position of the resultant force at the critical sections is outside the middle third of the dam. The present increased reliance on the rock anchor installation results in a resisting structure acting outside the parameters of a traditional gravity dam. For traditional gravity dams, the position of the resultant force is recognised as a more useful performance indicator than safety factors against overturning. Given the limited amount of information provided by the designer, the tensions in the rock anchors under the usual load condition are assumed to be less than the service loads listed on the drawings. As such, the resultant force would be located even further away from the middle third. Given the specific nature of the dam to resist overturning forces, the factor of safety against overturning becomes the only performance indicator in this regard.

Normal stresses in heel and toe: Stresses at the heel and toe of the dam are highly dependant on the actual tension forces in the rock anchors. Given the procedural directions indicated on drawings and specifications for the rock anchor installation, it appears as though the anchors were pre-tensioned in the rock but released in the concrete prior to final grouting. Without additional information it would seem that there exists a scenario whereby estimate-able tensions will not be present in the rock anchors until rotations in the dam begin to occur. If this is the case, the stress values in the toe will exceed the allowable limits and the dam will be operating outside its performance indicators.

Shear stresses: The DSG states that: *"In rigid body analysis, the net calculated driving force is usually considered to be uniformly distributed over the zone of calculated compression" (DSG January 1999 pg. 9-7).* As the zone of compression is dependant on estimate-able values of tension in the rock anchors, the shear strength in the lower sections of concrete and rock should be taken as zero.

Sliding Factors: Sliding factors are equated with the available shear strength over the net driving force. This is generally considered to require checks with respect to limits of either sliding or shear. As such the resisting mechanisms in the lower sections of the dam become dependant on sliding at the dam foundation interface and shear in the rock anchors. Depending on the interpretation, the equations listed on the drawings appear to be conservative in this respect.

Observable Conditions: To our knowledge, measure records do not exist and no attempt has been made to map either monumental displacements in the dam or the hydrostatic gradient. Our site observations were made during a transitory point in the reservoir filling and provide little value in terms of the dam's performance.

9.7 Acceptance Criteria

In general, the level information and documents leads us to the following conclusions:

1. The requirements for residual sliding factors are deemed to be met (*RSF > 1.5 DSG January 1999 pg. 9-11*).
2. Without additional information, overstressing in the rock is deemed to be a potential concern.

Reservoir & Environment (DSG Section 10)

10.1 Reservoir Debris and Ice: Accumulation and management of excessive debris is considered unlikely and is not an issue at this time. Ice movements and accumulations appear to have been well accounted for in the listed loads for the new dam structure. However the tension envelope of the rock anchors will have to be confirmed.

10.2 Reservoir Rim: The majority of the reservoir rim is a natural rock formation with mild to moderate gradient, and no history of instability. The Geotechnical Investigation indicates three separate locations where the reservoir level may rise above the level of the bed rock and into the earth overburden. The location of the new south berm has been identified as the only area of concern and is deemed to have been adequately protected with the new berm and cutoff wall.

10.3 Water Quality: Given the location of the dam, the reservoir and dam structure are not deemed to be subjected to man-made chemicals. The reservoir has not historically been subjected to detrimental mineral depositions or marine salts.

10.4 Sedimentation and Silting: Silt accumulation behind the dam has historically not been a problem

10.5 Reservoir Drawdown Capability: Marginal drawdown capabilities can only be said to exist via the pump housing for the existing water supply system. It was noted in the previous DSR that, during the operation of the reservoir at the design head, it may be prudent to drawdown the reservoir under extreme ice load conditions. It is currently unknown whether the drawdown capabilities of the pump house have ever been established. Rapid drawdown capabilities cannot be said to exist.

10.6 Ecology: No significant ecological hazards are known to exist.

Construction (DSG Section 11)

The DSG section on Construction predominantly deals with the responsibilities of the engineer during construction. In essence the Engineer is responsible for ensuring that the work is carried out in conformance with the design and specifications. The engineer should be on site to review, mediate, document and approve: all key phases of the work; any deviation from the design intent; and any required deviations from the specifications. *"Documentation should include photographs, written explanations, as-built drawings and results of all quality control tests with date and test sample location"(DSG January 1999 Pg. 11-1).*

Such information represents the basis for the only relevant record of the constructed dam and as such should have been provided to the owner as part of the permanent file and for future reference. As this information has not been forwarded to us we cannot comment on the completeness of this part of the DSG.

OPERATION, MAINTENANCE AND SURVEILLANCE (DSG SECTION 3)

The 2006 dam raising has generally accepted the original passive operation of the dam structure. As such the previous DSR is still considered to be valid.

Still of primary concern is the lack of any available permanent record file. Such files *"should be maintained as an ongoing history available for general use and reference" (DSG January 1999 pg 3-2)*. The file should contain the following:

- Operation, Maintenance and Surveillance Manual (OMS).
- Instructions given by regulatory agencies, dam designer or other authority, and the record of compliance and details of any remedial action.
- As-built drawings from original construction and all subsequent construction phases
- Readings on any instrumentation and summary reports of dam performance.
- All design data including both original and modifications or revisions
- All inspections and Dam Safety Reviews
- Chronological history of the structure.
- Photographic record

Given the currently completed dam raising, additional design and construction related documents would form a large part of the permanent file. These documents do not appear to have been supplied to the City.

As with the previous DSG the Permanent Record File OMS and logbook have yet to be initiated.

EMERGENCY PREPAREDNESS (DSG SECTION 4)

"An Emergency Preparedness Plan (EPP) shall be prepared, tested, issued and maintained for any dam including a dam under construction, or a cofferdam, whose failure could be expected to result in loss of life as well as for any dam for which advance warning would reduce upstream or downstream damage" (DSG January 1999 pg. 4-1). The EPP should include the following:

- Emergency identification and evaluation
- Preventative actions (where available)
- Notification procedure
- Notification flowchart
- Communication systems
- Access to site.
- Response during periods of darkness

- Response during periods of adverse weather
- Sources of equipment
- Stockpiling supplies and materials
- Emergency power sources, if required
- Inundation maps
- Warning systems (if used)

As with the previous DSG an EPP has yet to be formulated in draft or otherwise.

COMPLIANCE WITH PREVIOUS REVIEWS (DSG SECTION 2)

1. Dam Safety Inspections have not been completed within the recommended time frame.

2. No record of subsequent underwater inspections exists.

3. The 2006 earth works supersede previous concerns with the earth embankment structures.

4. The dam is still in non-compliance with the requirements of Sections 3 and 4 of the DSG.

5. The current Dam Safety Review has been initiated in response to the just completed with respect to the raising of the level of the reservoir.

4 SUMMARY

Based on our inspection, review, and analyses, we summarize the results of the DSR as follows:

1. In accordance with Section 1 of the DSG, the dam continues to operate under a High Consequence Category.

2. The raising of the earth embankments and concrete gravity dam section was completed in 2006. The design review for the new dam structure has been limited to visual information obtained on site and tender documents provided by the design engineer (Trow). Design calculations, material testing reports and site reports do not appear to be on record with the city. These documents were requested of, but not supplied by, Trow. These documents belong in the permanent file and are required to complete this, and subsequent, Dam Safety Reviews.

3. Rock Anchors were added in 2005. Based on the information provided, there is enough evidence to establish reasonable doubt that rock anchors were properly pretensioned such that they would behave as desired under ice loading conditions. Because of the limited information provided by Trow, we cannot confirm this with certainty.

4. No permanent instrumentation was added during the 2006 dam raising. The monitoring and instrumentation of the dam does not appear to meet the recommendations of the DSG

5. As per the previous DSG, the dam is still in non-compliance with the requirements of Sections 3 and 4 of the DSG. The following documents do not exist at this time:

   - Permanent File
   - OMS Manual
   - Logbook
   - Emergency Preparedness Plan

8. A Dam Safety Inspection (DSI) should be conducted in 2007. This is essentially a yearly non-invasive review comprising a visual inspection to identify any changes in condition, or any observed concerns. The 2007 DSI should follow-up on spillway leakage observed in October 2006.

9. An underwater inspection of the submerged structures should be done in 2007. This inspection should be coordinated with, and be under the direction of, the DSI recommended in Item 5, above.

10. A future DSR should be scheduled for no later than 2013.

7. RECOMMENDATIONS AND REQUIRED ACTION

1. The current lack of design and construction documentation is of primary concern. The absence of this documentation has resulted in specific items being labelled as incomplete and/or non-compliant with respect to the DSR. The City should ensure that all relevant as built records, design calculations, site reports are obtained from the engineer of record (Trow) and kept as part of the permanent file (see below).

2. Discrepancies with the 2005/06 design and 2005 geotechnical investigation report should be formally justified.

3. The design review for the embankment structure has been labelled as incomplete. Either sufficient documentation of the design and construction will have to be provided or an independent analysis will have to be prepared.

4. The engineer of record will have to provide formal justification of the performance envelope for the rock anchors. The current level of information indicates that overstressing of the rock foundation will occur under the usual load case. In the event that sufficient information is unavailable, additional analysis will have to be performed and safety measures implemented (if required).

5. The lack of permanent instrumentation should be formally justified or the long term performance of concrete cutoff wall will have to be adequately accounted for in the design of the earth embankments (yet to be provided).

6. The dam is still in non-compliance with the requirements of Sections 3 and 4 of the DSG. The following documents need to be developed and maintained.

   - Permanent File
   - Operation, Maintenance & Surveillance Manual
   - Logbook
   - Emergency Preparedness Plan

7. A Dam Safety Inspection (DSI) should be conducted in 2007. This is essentially a yearly non-invasive review comprising a visual inspection to identify any changes in condition, or any observed concerns.

8. An underwater inspection of the submerged structures should be done in 2007. This inspection should be coordinated with, and be under the direction of, the DSI recommended in Item 5, above.

9. A future DSR should be scheduled for no later than 2013.

Should there be any questions, please contact the undersigned.

Yours sincerely,

Concentric Associates International Incorporated

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Allan Murray P. Eng.

APPENDIX A: SITE PHOTOGRAPHS