Structural Design and Factors of Safety

Technical Bulletin

Ontario Ministry of Natural Resources

August 2011

This publication is available online at:
Ontario.ca/dams

Ces documents sont offerts en anglais seulement en raison de leur nature très technique; ils sont exemptés de publication en français par Règl. de l'Ont. 411/97 pris aux termes de la *Loi sur les services en français*. Pour obtenir de l'aide en français, veuillez communiquer avec Carrie Hoskins du ministère des Richesses naturelles à l'adresse: carrie.hoskins@ontario.ca.

The Lakes and Rivers Improvement Act (LRIA) provides the Minister of Natural Resources with the legislative authority to govern the design, construction, operation, maintenance and safety of dams in Ontario. The Lakes and Rivers Improvement Act Administrative Guide and supporting technical bulletins have been prepared to provide direction to Ministry of Natural Resources staff responsible for application review and approval and guidance to applicants who are seeking approval under Section 14, 16 and 17.2 of the LRIA. All technical bulletins in this series must be read in conjunction with the overarching Lakes and Rivers Improvement Act Administrative Guide (2011).

Structural Design and Factors of Safety

Table of Contents

1.0 General

This technical bulletin has been prepared to provide direction to MNR staff and guidance to dam owners in meeting standards for structural design and factors of safety for concrete gravity dams and is to be used when considering applications for approval under Section 14, 16, and 17.2 of the Lakes and Rivers Improvement Act (LRIA).

The standards and criteria outlined within this technical bulletin are intended to apply to dams (including the control structure and all appurtenant facilities) that hold back water in a river, lake, pond or stream to raise the water level, create a reservoir to control flooding or divert the flow of water; and are not intended to apply to other works subject to LRIA approval such as water crossings, channelizations, enclosures, pipelines and cables.

This technical bulletin must be read in conjunction with the Lakes and Rivers Improvement Act Administrative Guide (2011) and the Ministry of Natural Resource's Classification and Inflow Design Flood Criteria Technical Bulletin.

2.0 Loading Combinations

The loading conditions that a structure may encounter during its service life are grouped into the load condition categories of Usual, Unusual, or Earthquake. Usual loads refer to loads and load combinations that can be expected to occur frequently during the service life of the structure (i.e. annual probability greater than or equal to 0.10). Unusual Loads refer to loads and load combinations that are of infrequent occurrence (i.e. annual probability less than 0.10). Table 1 outlines the minimum sliding safety factors (MSSFs) for concrete dams.

The stability of gravity concrete dams shall be assessed under the following loading combinations:

1. Usual Load (Summer) includes the following loads acting in combination: Dead load; Hydrostatic Load (maximum normal operating level); Soil Load; and Uplift;
2. Usual Load (Winter) includes the following loads acting in combination: Dead load; Hydrostatic Load (winter operating level); Ice Load; Soil Load; and Uplift (see note 4);
3. Unusual Load (Flood) includes the following loads acting in combination: Dead Load; Hydrostatic Load (IDF flood level); Soil Load; and Uplift Load;
4. Unusual Load (Winter) includes the following loads acting in combination: Dead load; Hydrostatic Load (winter operating level); Ice Load (see note 5); Soil Load ; and Uplift;
5. Earthquake loading includes the following loads acting in combination; Maximum Design Earthquake, Dead loads, Hydrostatic Load (maximum normal operating level); Soil Load; and Uplift; and
6. Post-earthquake Load includes the following loads acting in combination: Dead load; Hydrostatic Load (maximum normal operating level); Soil Load; and Uplift.

Table 1 - Minimum Sliding Safety Factors for Concrete Dams

Loading Combination	Unbonded	Bonded
Usual	**1.5**	**2.0**
Unusual	**1.3**	**1.5**
Earthquake	**1.1**	**1.3**
Post-Earthquake	**1.1**	**NA**

Notes:
1. The same Minimum Sliding Safety Factors (MSSF) apply to all dam hazard classifications
2. The use of an assumption of a bonded or partially bonded foundation may be used with conservative estimates of the available shearing resistance based on geotechnical testing at the site or extrapolated from testing at nearby sites using the same methods of construction.
3. The Unusual Load (Flood) MSSFs are the same regardless of the frequency of the IDF.
4. For Usual Load (Winter), use a 75 kN/m (5 kips/ft) ice load, applied 0.3m below the normal winter water level.
5. For Unusual Load (Winter), the ice load is to be based on the Canadian Electrical Association (CEA) Technologies – Static Ice Loads on Hydro-electric Structures Report T002700-0206 (August 2003) or equivalent research that provides a site specific ice load or based on ice loads measured at other similar sites (i.e. published data).
6. Ice loadings may be reduced by 50% in the evaluation of steel gates and steel stoplogs. An ice loading of 29.0 kN/m (2.0 Kips/ft.) may be used for the evaluation of timber stoplogs.
7. For flood conditions, the flood discharge capacity available and the calculated inflow design flood level shall be based on a reasonable assessment of dam operations considering the operating plan and shall take into consideration factors such as: accessibility during high flows, the potential for failure of electrical and mechanical systems, and inspection and maintenance programs.
8. Unusual Load (Winter) does not apply to existing low and moderate hazard potential classification concrete gravity dams that have been operating with no signs of distress and where operating conditions have not, and are not anticipated to change. Documentation of satisfactory historical performance is required, e.g. inspections by a Professional Engineer.
9. An earthquake or post-earthquake stability assessment need not be undertaken for existing dams that have a low and moderate hazard classification under a sunny day failure.
10. In the earthquake stability assessment of concrete gravity dams, methods of analysis can range from pseudo-static, pseudo-dynamic, response spectra and time history methods. In general, the pseudo-static method can be used as a basic screening approach to assess the dam stability against the MFFSs as shown in the above Table 1.

3.0 Sliding Stability Analysis for Concrete Gravity Dams

Sliding stability analysis should be undertaken for the concrete gravity dam as an entire unit and for sections of the dam (e.g. piers).

The steps involved in the analysis are as follows:

Step 1:

Assess safety factors under Usual, Unusual, and Earthquake loading using unbonded shear resistance. The basic friction angle [˚] may be selected from literature based on the typical basic shear strength values for the contact rock type. Roughness estimates will typically require an evaluation and/or a review of construction photographs. If the safety factors for the various loading combinations are adequate, proceed to Step 5. Otherwise proceed to Step 2.

Step 2:

For dams with bonded foundations assess safety factors under Usual, Unusual, and Earthquake loading using bonded shear resistance values (friction angle [˚] and cohesion [MPa]) selected from literature based on the contact rock type. If the safety factors are adequate proceed to Step 3. Otherwise proceed to Step 4.

Step 3:

Confirm the degree of bonding and the existence of a cohesive bond by testing and assess safety factor using conservative estimates of friction angle and cohesion strength based on test results. The results of the analysis must demonstrate that the structure has a safety factor in excess of 1.0 in the absence of a cohesive bond. If safety factors are adequate, proceed to Step 5. *Otherwise proceed to Step 4.*

Step 4:

If safety factors for Usual and Unusual loadings are inadequate, repeat analysis with proposed remedial action alternatives (e.g. lowered reservoir level, anchors) until safety factors are adequate. If safety factor for Earthquake loading is inadequate, assess post-earthquake safety factor using unbonded shear resistance. If post-earthquake safety factor is adequate, evaluate damages to dam structure (deformation and stresses). If post-earthquake factor of safety is inadequate, repeat analysis with proposed remedial action alternatives until the safety factor is adequate.

Step 5:

Analysis complete; Dam structures meet stability criteria.

The analysis should also examine construction joints or other areas of severe concrete deterioration as well as failure planes through the foundation.

4.0 Position of the Resultant

For the Usual Load cases, the Resultant should be in the middle third of the surface being analyzed. For new dams this is achieved by design. For existing dams this requirement may be waived if sliding factors of safety are met, and provided that the resultant is within the base of the dam and limits on allowable bearing stresses are not exceeded.

For the Unusual Loading case, the Resultant may be outside the middle third provided that the sliding factors of safety are met, and provided that the resultant is within the base of the dam, and the limits on allowable bearing stresses are not exceeded.

For the Earthquake Loading case, the Resultant may be located outside the base.

Uplift pressures vary linearly from full headwater to tailwater level. Uplift pressures may be reduced if the dam has adequate pressure relief (either natural or installed) and monitoring (instrumentation) systems and the results of the monitoring systems show that the pressure relief systems are functioning adequately.

Specific density for silt behind a dam should be taken as 1.4 for horizontal loading, 1.9 for vertical loading.

5.0 Other Considerations

Generally, post-tensioned anchors should not be used as a primary means to stabilize new concrete structure dams. Where post-tensioned rock anchors are used to increase resistance to sliding and/or overturning resistance of the dam, the design must account for the characteristics of the foundation material established by field investigation, which may include in-situ testing and sampling or visual inspections. The specifications for anchoring systems must include double corrosion protection in accordance with standards established by the Post-Tensioning Institute and on-site lift-off testing or other integrity testing to demonstrate effectiveness. For dams with a Hazard Potential Classification of High or Very High, with potential loss of life, the safety factor under Usual Loading conditions should not be less than 1.0 without post-tensioned anchors. Where the factor of safety under Usual or Unusual Loading conditions is less than 1.0 without post-tension anchors, the design of the anchor system shall include redundancy to provide a factor of safety of 1.0 or more with the failure of any single anchor.

Suitable water-tight expansion and contraction joints should be provided.

Glossary of Terms

Appurtenant Facilities: Means structures and equipment on a dam site including, but not limited to, intake and outlet structures, powerhouse structures, tunnels, canals, penstocks, surge tanks and towers, gate hoist mechanisms and their supporting structures, spillways, mechanical and electrical equipments, water control and release facilities.

Dam: For the purpose of this technical bulletin, a dam is defined as a structure that is constructed which holds back water in a river, lake, pond, or stream to raise the water level, create a reservoir to control flooding or divert the flow of water.

Dam Owner: The owner of a dam, structure or work and includes the person constructing, maintaining, or operating the dam, structure or work; (“proprietaire”).

Design Flood: The maximum flow in a stream or river that a dam is designed to pass safely.

Foundation: The soil or rock upon which the structure or embankment rests. An alternative definition is similar to footing.

List of Acronyms

CEA	Canadian Electrical Association
IDF	Inflow Design Flood
LRIA	Lakes and Rivers Improvement Act
MNR	Ministry of Natural Resources (provincial)
MSSF	Minimum Sliding Safety Factors