Spillways and Flood Control Structures

Technical Bulletin

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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).

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1.0 General

This technical bulletin has been prepared to provide direction to Ministry of Natural Resources (MNR) staff and guidance to dam owners in the identification of standards and criteria for spillways and flood control structures 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 Critical Design Factors

During Dam Safety Reviews (DSR) of existing dams or the design of new dams, it is important to ensure that flow control structures are in good operating condition, and that their capacity is sufficient. The following should be considered:

1. The hydraulic capacity of the structure is correctly evaluated;
2. The flow control equipment will be functional up to the peak Inflow Design Flood (IDF) (during a flood or after an earthquake if applicable);
3. The capacity of the channels heading to the flow control are not likely to be obstructed during at the passage of the flood;
4. Proper operating rules are in place and well understood; and
5. Safe access and power supply to the control structures are maintained at all times. This can be provided by alternate power sources or redundancy of control system components.

3.0 Spillways and Other Discharge Facilities

3.1 Spillway Purpose

The primary purpose of a spillway is to discharge flows that cannot either be used immediately or stored in a reservoir for future use. The spillway is used to prevent surcharge of the reservoir water level above the IDF elevation including providing for freeboard requirements.

3.2 Classifying Spillways

Spillways can be classified, based on the frequency of use, as either “service” or “emergency” spillways.

Service Spillways

A service spillway is the primary flood discharge structure that would be available to handle discharge under any conditions. The spillway is operated either automatically or by personnel assigned to the site.

The spillway should be designed so that operation could be considered to be an everyday situation. This would require that any gate be easily operated and that energy dissipation does not result in damage to the structure or discharge channel.

Service spillways can be gated or ungated and typically include overflow, side channel, shaft or chute-type structures.

Emergency Spillways

Emergency spillways (also known as auxiliary spillways) are used during unusually high flow conditions.

Operations of an emergency spillway may result in some damage to structures or erosion in the discharge channel. Operating procedures may also require mobilization of additional equipment and personnel in excess of that normally at the dam. Examples of emergency spillways include earthcut and fuse plug channels, and in some cases, may incorporate gate controlled or stoplog sluice structures.

Other Discharge Facilities

Other discharge facilities, such as low level outlets, have a number of functions depending on the specific circumstance of the particular project. The capacity of the discharge facilities is determined by considering all of the expected operating requirements.

Typical functional requirements include:

1. Release of minimum flows to sustain the aquatic regime, surface water drinking water supplies and provincial water quality objectives. This function may be needed when the flow release through a powerhouse is interrupted or when other discharge facilities are not available;
2. Emergency discharges for reservoir drawdown. This capability is often overlooked but is an important safeguard when considering mitigation procedures in the event of faults in the dam or foundations. Emergency discharge capability should be considered as an important element of the design of any new dam and reservoir facility;
3. Controlled releases are often required during initial impoundment of a reservoir to control the rate of filling. This function is intended to allow for monitoring of the dam and foundations under the increasing load and pore pressure. The design

often requires that the reservoir level be held steady for flood inflows in the order of a 10 year return period event;

4. Primary flow diversion works for releasing downstream water demands, as in the case of many irrigation and water supply reservoirs where another outlet may not be needed; and
5. Provisions to by-pass or divert flows, which is normally required during construction of a dam and for the maintenance of the spillways. The construction period role would occur as the diversion tunnel is being closed at the start of reservoir impoundment.

Discharge works such as low level outlets can be used during floods, provided that operation is not impaired by high tailwater levels or the operation of other spillways. This would normally be a supplemental capacity to the service spillway discharge capability.

For power dams, discharge facilities can include the powerhouse capability although this is limited by the operations within the power system and the demand for plant output. Low level outlets must meet the various functional requirements of the facilities and for use when the powerhouse is not in service.

It should be assumed that the electrical transmission system may suffer serious damage during the storm that generated the IDF. Therefore, the power plant must be assumed to be out of operation between the first day of the storm and the time it takes to repair the transmission system. Therefore powerhouse discharge facilities should be restricted to the speed-no-load capacity included to meet the IDF.

In some cases, the tailwater levels during the passage of the IDF may lead to flooding of the power plant turbine floor. In this situation, the power pant must be assumed to be shut down until the tailwater recedes.

4.0 Design Considerations

4.1 Design for Debris and Ice During Flood Events

Design of spillways must consider requirements for passage of debris and ice during flood events. Significant amounts of debris comprised of trees, brush, and other floating material such as ice and logs can collect and obstruct a spillway structure entrance, resulting in significant loss of discharge capacity. Debris control can be achieved by the alignment of the spillway entrance, use of a floating debris boom, trash sluices, and by routine maintenance such as reservoir clearing.

4.2 Sediment Transport

Sediment transported during a flood must also be considered in spillway design. This is particularly the case for energy dissipating facilities. Gravel and boulders transported during a flood can cause significant damage to the concrete surfaces of spillway structures and stilling basins as a result of abrasion and impact caused by the turbulent eddying. Where sediment transport is a significant consideration, special design features may be incorporated such as armoring of a spillway surface or modifications to the layout and design of structures.

For further information on design considerations, water control, conveyance and energy refer to CDA's Technical Bulletin: Hydrotechnical Considerations for Dam Safety (2007).

5.0 Freeboard

Freeboard is defined as the minimum vertical distance that is required between the reservoir level and the crest of the containment structure or the impervious core of an embankment structure. Freeboard is required to protect the structure from overtopping by large waves including allowance for reservoir setup, wave run-up, floods, settlement, protection of the impervious core of embankment structures and other factors that could influence the level of the reservoir.

5.1 Factors and Criteria Influencing Freeboard

A number of factors influence the magnitude of the freeboard required to prevent overtopping of dams. These include:

1. wind effects (wave run-up and wind set-up);
2. landslide effects; and
3. earthquake effects.

Depending on the losses associated with dam failure, the following criteria should be considered when evaluating minimum freeboard for dams:

1. No overtopping of the crest of the dam by 95% waves caused by the most critical wind with a return frequency of 1:1000 with the reservoir at its normal maximum operating level;
2. No overtopping of the crest of the dam by 95% of the waves caused by the most critical wind with a return frequency of 1:2 with the reservoir at its maximum level during passage of the IDF normal maximum operating level; and
3. No overtopping of the impervious core by a still pond water level with the reservoir at its peak IDF operating level.

The largest calculated freeboard requirement must be adopted as the minimum freeboard.

5.2 Minimum Freeboard for Dams

The minimum required freeboard depends on the type of structure and the foundation/ abutment conditions.

For Low and Moderate hazard potential dams, minimum freeboard can be based on a risk analysis balancing the economics of potential damages that might result from a dam failure in comparison to the costs of increasing the height of the dam to prevent overtopping.

The freeboard must not be less than the following table of minimum freeboard requirements unless a comprehensive analysis and assessment is undertaken.

Table 1 - Minimum Freeboard for Dams

Reservoir Fetch (Length)	Freeboard
Under 200 m	300 mm
Up to 400 m	450 mm
Up to 800 m	600 mm
Over 800 m	Comprehensive assessment required

5.3 Accounting for Earthquake and Landslide Effects

In a more comprehensive assessment of normal freeboard requirements, the following combinations may also need to be evaluated:

1. Earthquake effects (wave run-up + dam crest settlement);
2. Landslide effects (wave run-up + water level rise due to displacement); and
3. Seiches.

If any of these combinations produces a freeboard requirement greater than that given by the wind effects alone, the greater value must be adopted. In estimating the effects from this event, the reservoir should be considered to be at the normal maximum operating level with reservoir set up being produced by a nominal 1:5-year wind.

The crest of the dam must be such that, following the Design Basis Earthquake (DBE) the crest of the dam is above the:

1. normal maximum reservoir operating level plus an allowance for reservoir setup and wave run up due to the effects of a nominal 1:5-year wind plus an allowance for crest settlement due to earthquake; and
2. normal maximum reservoir operating water level plus an allowance water level rise due to displacement caused by a landslide.

5.4 Minimum Freeboard under Inflow Design Flood Conditions

To determine the required minimum freeboard (wave conditions and wind set-up) during passage of the IDF, the most severe reasonable wind conditions for the reservoir at this maximum extreme water level based on the IDF must be used. As the IDF is generated by an exceptional storm with a relatively low probability of occurrence, it is not reasonable to expect that extreme wind will occur simultaneously with the peak of the

IDF. Therefore, the maximum wind to be expected during the passage of an IDF should not exceed a 1:100 AEP (Annual Exceedence Probability).

Conditions may be expected to be worse in the case of a small reservoir in a small watershed, where the maximum level in the reservoir will occur shortly after the end of the storm as compared with a large reservoir in a large watershed, where the maximum reservoir level will occur several days after the storm is over. For this reason, the criteria for selecting wind intensity are related to the delay between the end of the storm and the time of occurrence of the maximum reservoir level. The design wind intensity for determining the minimum freeboard under IDF conditions is provided below.

Table 2 - Design Winds under IDF Conditions

Duration Between the End of the Storm and the Time of the Maximum Reservoir Level	Wind AEP
Less than 6 hours	1:100
6 to 12 hours	1:20
12 to 48 hours	1:5
More than 48 hours	1:2

Under peak IDF conditions, some splash-over may be allowed where specific measures are included in the design to prevent erosion of the crest, downstream slope and toe of the dam.

5.5 Minimum Freeboard for High and Very High Hazard Potential Embankment Dams

The minimum freeboard required for High and Very High hazard potential embankment dams should be sufficient to meet all of the following criteria:

1. No overtopping of the crest of the dam by 95% waves caused by the most critical wind with a return frequency of 1:1000 with the reservoir at its normal maximum operating level;
2. No overtopping of the crest of the dam by 95% of the waves caused by the design wind as defined herein or, if information to calculate the design wind is not available, a critical wind with a return frequency of 1:100 with the reservoir at its maximum level during passage of the IDF;
3. No overtopping of the impervious core by the still pond water level can occur, including an allowance for reservoir setup under the effects of a 1:5 year wind with the reservoir at its normal operating level; and
4. No overtopping of the crest of the dam that could occur as a result of waves generated as a result of a landslide or earthquake induced seiche.

Overtopping may be allowed if it can be shown that such overtopping would not endanger the stability of the dam.

Freeboard must also be sufficient such that, under the normal operating and protracted flood conditions, with allowance for reservoir setup, the containment core of the structure is not overtopped.

5.6 Minimum Core Elevation

The impervious core of an embankment dam shall be designed such that it is not overtopped by the IDF water levels. The minimum impervious core elevation must meet the following criteria:

1. Possible settlement due to consolidation of foundations embankment material; and
2. Degradation of the impervious core due to frost action, weathering, and incidental loading such as traffic.

This standard is based on the principle that steady state or quasi-steady state water levels (i.e. excluding waves) should not exceed the top of the impervious core. However, for earth/rock fill dams that have been designed for overtopping, the minimum freeboard standard may be reduced or overtopping may be allowed provided that the integrity of the structure is not compromised.

The minimum crest elevation is then determined on the basis of the amount of cover needed to provide confinement and protection of the top of the impervious core to resist damage due to the effects of desiccation due to frost, vehicular traffic, etc. The thickness of core protection fill needed will vary depending on the characteristics of the site, climatic conditions and the frost susceptibility of the core materials.

5.7 Concrete Dams

Concrete dams situated on a bedrock foundation can usually resist overtopping without serious damage. Accordingly, the minimum freeboard requirement may be reduced or overtopping may be acceptable provided that the stability of the dam, its abutments, any ancillary structures and access to flow control structures are not compromised.

When the crest of a concrete structure is used as an access to outflow control structures, no overtopping should be permitted:

1. during the passage of the IDF. Judgment is required regarding the acceptability of allowing waves to splash over the structure. However, as a minimum, the freeboard should be designed to prevent overtopping by 95% of the waves generated by the effects of the 1:10-year wind;
2. under normal operating conditions, no overtopping of the crest of the dam by 95% of the waves caused by the most critical wind with a return frequency of 1:1000 with the reservoir at its normal maximum operating level;
3. as a result of waves generated by a landslide or the DBE

5.8 Steps to Determine Freeboard

The elevation reached by wave run-up against a structure is determined using the following steps:

1. Select the appropriate wind frequency;
2. Compute the wind set-up, which is the maximum reservoir surface tilting due to the effect of a sustained wind in a specific direction;
3. Compute the effective fetch for each structure;
4. Compute the resulting waves;
5. Compute the run-up of the breaking waves based on the slope and material of the structure.

5.9 Appropriate Procedures for the Determination of Freeboard

Wind data and frequency information appropriate for the calculation of freeboard are available for wind stations throughout Ontario from Environment Canada.

The Canadian Dam Association (CDA) and several United States agencies have produced documents and procedures that can be used to estimate the wind/wave effects required for determination of freeboard. Because of the probabilistic nature of wind and wave events, each of these procedures is designed to produce conservative results.

The most current of these are found in the United States Army Corps of Engineers Coastal Engineering Manual. A sample list of documents containing calculations that may be used is as follows:

1. Coastal Engineering Research Center, USACE. “Coastal Engineering Manual”. Washington DC. 2002.
2. Coastal Engineering Research Centre, USACE. “Automated Coastal Engineering System”. Vicksberg, MI. 1992. Computer Program.
3. US Department of the Interior, Bureau of Reclamation. “Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams”. ACER Technical Memorandum No. 2. Denver. 1992.
4. Construction Industry Research and Information Association. “Manual on the use of rock in coastal and shoreline engineering”. London. 1991.
5. Coastal Engineering Research Centre, USACE. “Shore Protection Manual”. Washington, DC. 1984.
6. Canadian Dam Association. “Technical Bulletin: Hydrotechnical Considerations for Dam Safety” Canadian Dam Association Dam Safety Guidelines. 2007.

5.10 Ice and Debris Considerations

In assessing the required freeboard, due consideration shall be made for the potential for debris and ice to reduce the discharge capacity of the flow control equipment during passage of the IDF.

Reservoir Ice

Reservoir ice can create a hazardous situation. The extent of the hazard potential would depend on the amount and thickness of ice and the characteristics of the dam and discharge facilities. For example, ice could jam or block discharge facilities, thereby reducing discharge capability, damaging facilities so that safe operation is not possible, or adding loads to the dam and appurtenant structures.

Reservoir Debris

If not restrained from reaching discharge facilities, reservoir debris could also create a hazardous situation. The extent of hazard would depend on the amount and size of the debris and the size and type of the discharge facilities. For example, debris could jam or block hydraulic conveyance structures, thereby reducing discharge capacity or causing damage that prevents safe operation of facilities. Debris booms are often used to restrain the floating debris from reaching discharge facilities. In areas where beavers or other animals are active, appropriate measures should be taken.

Glossary of Terms

Abutment: The end of a dam, or other structure, consisting of a wall or natural formation. An abutment wall is similar to a wing wall.

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 equipment, 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.

Debris Booms: Floating barriers used to collect surface debris and to warn boaters of the boom location.

Embankment: A bank of earth or rock constructed above the normal (natural) ground surface.

Emergency Spillway: The spillway that is designed to carry extraordinary flows such as the design flood.

Exceedance Probability: The probability that a specified level of ground motion or specified social or economic consequence of earthquake will be exceeded at a site or in a region during a specified exposure time, also Annual Exceedence Probability.

Freeboard for Bridges and Culverts: The freeboard is the distance between the design flood level and the edge of the pavement at the approaches to the bridge or culvert

Freeboard for Dams: The distance from normal maximum water level (i.e., full supply operating level) to the crest of a dam that provides for wave action without overflow.

Hydraulic: Relating to the flow of liquids particularly water.

Hydraulic Capacity: The maximum flow that a dam, spillway, or other structure can safely pass.

Impervious Core: The central portion of an earth dam made of an impervious material, such as clay, to prevent excessive seepage.

Inflow Design Flood: The maximum flood entering a reservoir for which the dam and reservoir are designed.

Seiche: A wave that oscillates in lakes, bays, or gulfs from a few minutes to a few hours as a result of seismic or atmospheric disturbances.

Spillway: The channel or passageway around or over a dam through which excess water is released or spilled without passing through the turbines.

Stilling Basin: A basin at the end of a dam containing a pool to dampen the flow energy resulting from discharge from the dam.

Tailwater: The downstream water (sometimes the downstream water depth).

List of Acronyms

AEP	Annual Exceedence Probability
DBE	Design Basis Earthquake
DSR	Dam Safety Reviews
CDA	Canadian Dam Association
IDF	Inflow Design Flood
LRIA	Lakes and Rivers Improvement Act
MNR	Ministry of Natural Resources
USACE	United States Army Corps of Engineers

References

Canadian Dam Association. “Technical Bulletin: Hydrotechnical Considerations for Dam Safety” Canadian Dam Association Dam Safety Guidelines. 2007.

Coastal Engineering Research Centre, USACE. “Automated Coastal Engineering System”. Vicksberg, MI. 1992. Computer Program.

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