Government of Newfoundland and Labrador
Department of Environment and Climate Change

TECHNICAL MEMO

Prepared By: Water Resources Management Division (WRMD)
Date: October 2023
Re: Increasing Freeboard

Background

This memo is part of a series of documents on dam emergency interventions. The focus of this memo is to provide guidance on increasing freeboard. As shown in the picture below, freeboard is the vertical distance between the maximum water surface and the dam crest.

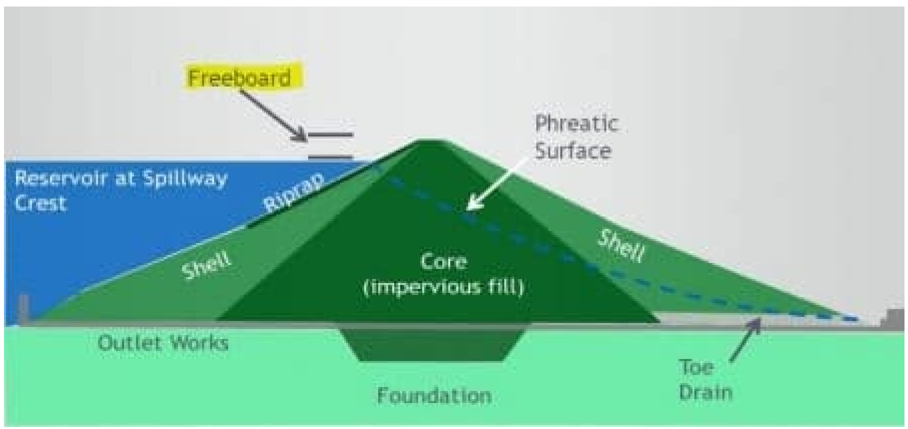

Figure 1: Freeboard in dams (British Columbia Dam Safety Self Directed Learning, n.d.)

The minimum freeboard for dams must be as follows:

Table 1: The minimum freeboard in dams (Spillways and Flood Control Structures, 2011)

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

Mode of Failure

The freeboard protects the dam against overtopping; water spilling over the dam due to waves generated by wind or landslides. Freeboard is vital for embankment dams because they are more susceptible to breaching and failure by overtopping. The overtopping can induce slope stability failure and erosion on the downstream slope. Thirty-one percent of embankment dam failures are due to overtopping. (Nigatu, Sigtryggsdottir, Lia, & Jabir, 2017)

The absence of adequate freeboard poses considerable flood risk to the development downstream of the dam. Overtopping can occur due to the malfunctioning of outlets, insufficient spillway capacity and settlement (Nigatu, Sigtryggsdottir, Lia, & Jabir, 2017). The purpose of increasing the freeboard is to protect the critical locations of the dam where overtopping is expected and prevent dam failure (Water control structures: selected design guidelines, 2004)

Procedure to increase freeboard

Designing a raised structure requires a thorough understanding of the dam, its construction and performance. An investigation of the embankment determines the condition of the dam, foundation and slope stability. The results from the study can be used to predict possible settlements due to the new structure. The investigation includes visual, geotechnical and subsurface inspection. (Tecnical Manual: Overtopping Protection for Dams, 2014)

Increasing the freeboard is a practical and cost-effective way to prevent dam failure. However, it should not be considered a low-cost substitute for another problem, such as a blocked spillway. It is vital to take into consideration essential design factors before implementing a method, such as: (Tecnical Manual: Overtopping Protection for Dams, 2014)

- higher load on an embankment may cause slope failure;
- Leakage from the structure may cause erosion and embankment instability; and
- Debris may damage the raised structure.

A Dam Safety Engineer and Dam Safety Regulators must assess the methods and design the structure based on the site condition: soil, topographic and climate.

The methods that can increase the freeboard are:

- **Construction of riprap berm on the upstream slope** - The riprap berm prevents waves from overtopping the dam by dissipating the energy of the water. It must be built by contractors who have experience in placing material on an embankment. It is an inexpensive method if the rocks are readily available. The drawback is that the weight of the berm could affect the stability of the slope. (Bohm, Blake, Groeneveld, & Donnelly, 2021)
- **Minor earthfill embankment** - A minor earthfill embankment can be a practical solution to raise the freeboard. A dam or geotechnical engineer must determine the type and volume of soil and compaction rate. However, a significant rise may reduce the stability of the dam. (Wechselberger, Martin, Scherman, & Shewan, 2018)
- **Concrete barrier** - A small dam raise as a parapet wall is feasible and reduces the possibility of waves to overtop the dam. A typical barrier is around 0.86 metres high. It can also be constructed off-site and transported to the dam. It is a costly method due to the required material and transportation. The weight of the barrier may also compromise the embankment stability. (Bohm, Blake, Groeneveld, & Donnelly, 2021)
- **Sheet pile barrier** - Another method to increase the freeboard is to use a sheet pile wall. The sheet pile is driven into the crest and the height can be adjusted as required. It does not take up much space across the crest. The sheet pile are not heavy and therefore does not affect the stability of the dam. However, it is expensive to transport the sheet pile to the site, and the process of driving the sheet piles into the crest may expose parts of the dam to the freeze and thaw cycle. (Bohm, Blake, Groeneveld, & Donnelly, 2021)
- **Sandbag dyke** - The sandbag dyke is a simple method to increase the freeboard. The bags are half-filled with sand, clay or silt and are arranged to form a wall. Polyethylene sheets are placed within the dyke to reduce seepage. Building the dyke does not require much technical expertise and is a reasonably quick process. However, the weight of the dyke may be a cause of concern for the dam stability.

- **Inflatable Flood Barrier** - It is the simplest method to prevent overtopping. Inflated flood barriers are flexible cylindrical tubes filled with water to create a flood wall. The tubes allow end-to-end connection to create a continuous barrier. The installation is a quick and easy process. It can be set up on any surface and the inflatable tubes conform to the terrain. In addition, it takes minimal storage space and is reusable. (Inflatable Flood Barriers, 2019) The inflatable tubes are usually available in hardware stores.

Building a sandbag dyke

The sandbag dyke is easy to implement and provide immediate protection against overtopping. This method can be used as a temporary solution while long-term and permanent solutions are evaluated and designed. The following steps illustrate the construction of the sandbag dike: (Emergency Measures Organization - Resources and Brochures)

- Materials
  - Fill the sandbags with sand, clay or silt to half capacity and tie the bag
  - Use polyethylene sheets to reduce the rate of seepage of water through the dike

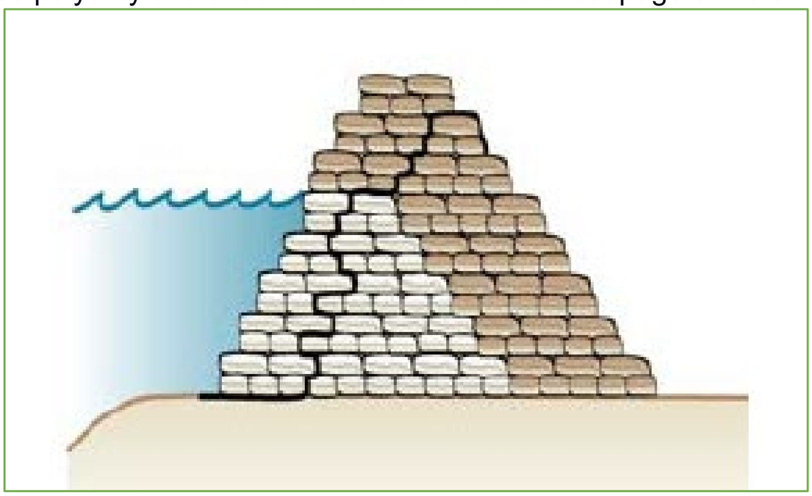

Figure 2: Polyethylene is used to reduce seepage. (Emergency Measures Organization - Resources and Brochures)

- Size of dyke
  - The required height should be 2 feet (0.6 metres) of freeboard [2 feet or 0.6 metres higher than the water surface]

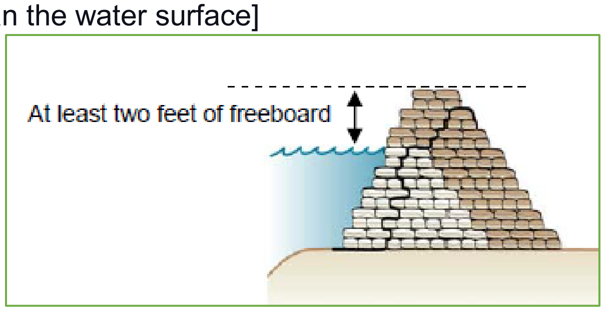

Figure 3: Required freeboard for dyke. (Emergency Measures Organization - Resources and Brochures)

  - The width of the dyke should be 2 feet (0.6 metres) greater than the height.

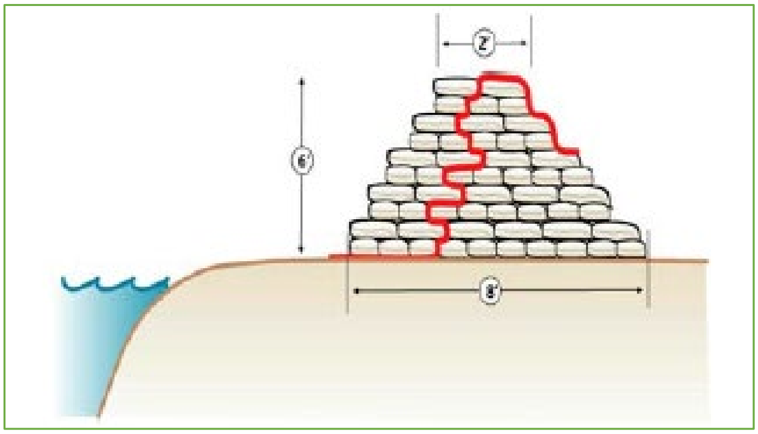

Figure 4: Required width of the dyke. (Emergency Measures Organization - Resources and Brochures)

- The sandbags will compact as it gets wet and it reduces the freeboard. Add three to four inches of sandbag to account for the compaction.
- Consult an Engineer for a dyke higher than 6 feet (1.8 metres) due to the presence of high water pressure.

- Prepping location of the dyke
  - Remove snow and ice at the location where the dyke is to be built
  - Abstain from constructing the dam on porous land to prevent water from flowing under the barrier
  - Dig a trench that is one sandbag deep and two sandbags wide if possible

- Constructing the dyke
  - The first layer of bags on the surface of the crest must be placed parallel to the water with the closed-end against the flow (see Figure 5). Within the trench, the sandbag must be perpendicular to the flow.

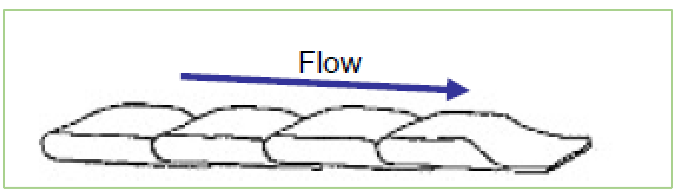

Figure 5: First layer of dyke. (Emergency Measures Organization - Resources and Brochures)

- The bags must overlap each other; that is, the filled part lies on the empty part of the previous bag.
- The bags are compacted using the feet.
- Offset the bags to create a brick pattern (see Figure 6).

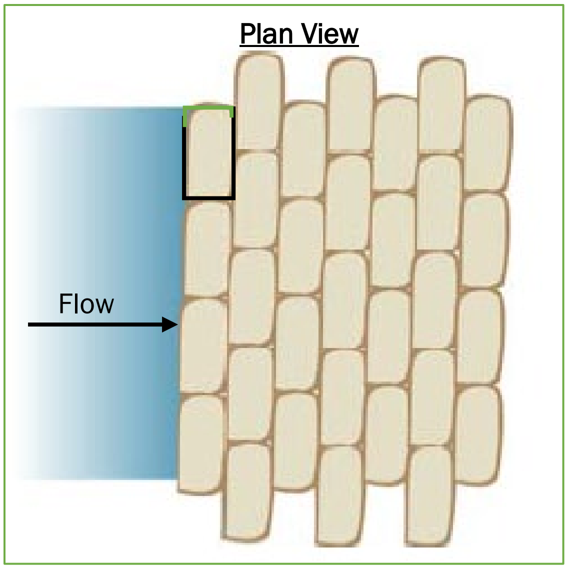

Figure 6: Placement of sandbags for dyke. (Emergency Measures Organization - Resources and Brochures)

- Rotate the sandbags by 90 degrees for the second row and the closed end must face the river as represented by the black line on the drawing (see Figure 7).

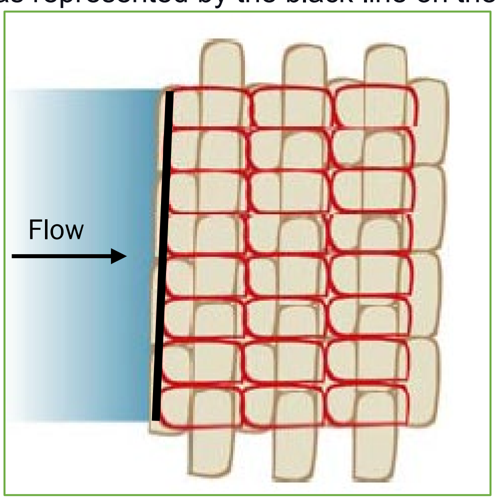

Figure 7: Placement of sandbags for subsequent rows for dyke. (Emergency Measures Organization - Resources and Brochures)

- For each subsequent row, change the direction of the bags from parallel to perpendicular.
- For every second row, the sandbags should be set back to a quarter of the sandbag width on both sides of the dyke to produce a step-like appearance (see Figure 8).

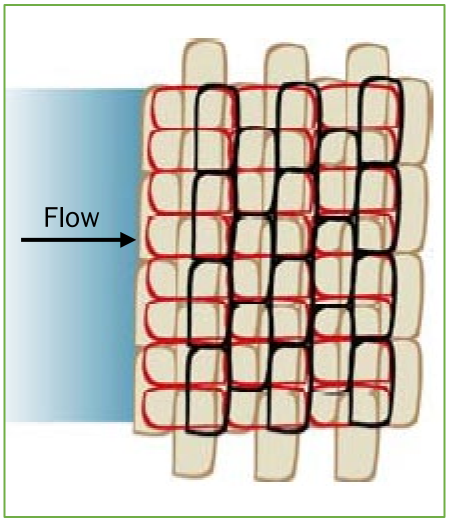

Figure 8: Sandbag set back for every second row. (Emergency Measures Organization - Resources and Brochures)

- Make use of six millimetre polyethylene in three-metre wide rolls on the upstream side of the dyke.
- Work the polyethylene sheet between the rows of the sandbag such that there are two layers of sandbag protecting the polyethylene sheet from punctures (see Figure 9). The maximum depth of the polyethylene sheet should be the minimum of the depth of three sandbags or a quarter of the cross-section of the dyke.
- The sheet should extend beyond the dyke on the upstream side.

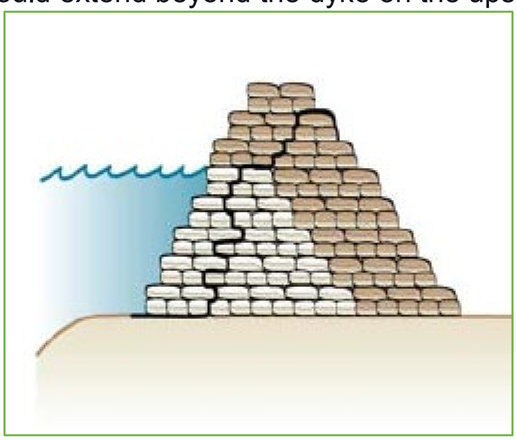

Figure 9: Placement of polyethylene sheet in dyke. (Emergency Measures Organization - Resources and Brochures)

- If more than one height of polyethylene sheet is required, the sheets should overlap at least two feet or 0.6 metres (see Figure 10).

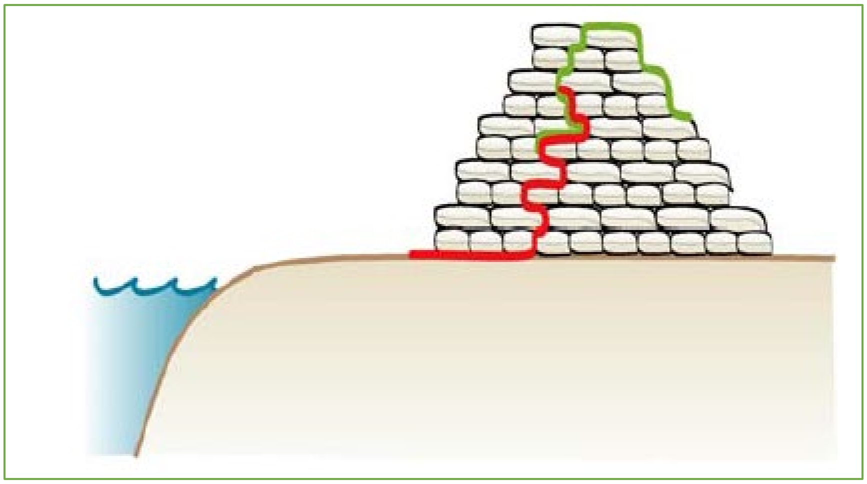

Figure 10: Placement of polyethylene sheet when more than one sheet is used. (Emergency Measures Organization - Resources and Brochures)

Recommendations

- Pumps must be readily available as an emergency plan since high water pressure can force water to seep through the dyke or bubble through the ground. (Wechselberger, Martin, Scherman, & Shewan, 2018)
- Implement an alarm system that is triggered when the water level exceeds a defined limit. It will provide time to implement evacuation procedures. (Wechselberger, Martin, Scherman, & Shewan, 2018)
- Update the Emergency Response Plans for the region.
- For sandbag dykes: (Emergency Measures Organization - Resources and Brochures)
    - Remove sandbag dyke with the same caution that it was placed.
    - Wear Personal Protective Equipment (PPE) during the construction of the dyke.
    - Follow the proper sandbag handling techniques:
        - Do not bend more than 20 degrees when holding the sandbags;
        - Keep the sandbag below the shoulder, above knees and close to the body; and
        - Do not throw sandbags.

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