Government of Newfoundland and Labrador
Department of Environment and Climate Change

TECHNICAL MEMO

Prepared By: Water Resources Management Division (WRMD)
Date: October 2023
Re: Sand Boils

Background

This memo is part of a series of documents on dam emergency interventions. Its focus is to provide guidance on sand boils. A boil is the deposit of sand particles in a conical shape due to internal erosion in the foundation layer caused by high seepage forces. Figure 1 illustrates the formation of a sand boil.

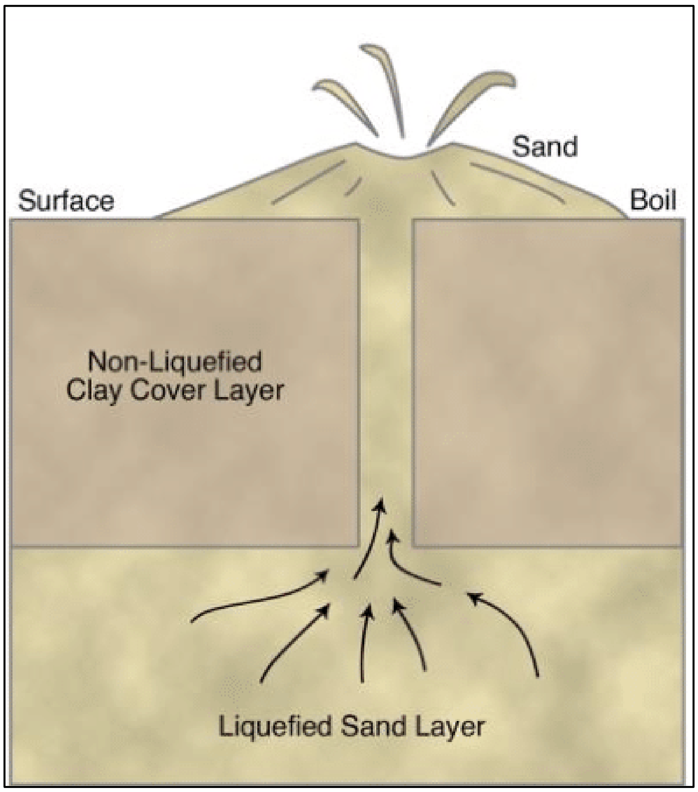

Figure 1: Formation of a sand boil (Larisch, 2019)

A boil is formed when a pervious layer (sand or gravel) in the foundation creates a pathway for seepage. The pervious layer is usually confined with a lower permeability clay blanket on top and the bedrock at the bottom to form an aquifer. The sand or gravel layer transfers a significant portion of the reservoir head downstream. The seepage pressure in the aquifer exerts a considerable uplift pressure on the clay blanket downstream of the dam. Failure starts when there are defects, or the blanket is thin. The pressure in the aquifer exceeds the weight of the overlying clay blanket in those vulnerable locations and breaks through the layer to form boils. (Training Aids for Dam Safety - Evaluation of Seepage Conditions, n.d.) Figure 2 illustrates seepage through a sand aquifer.

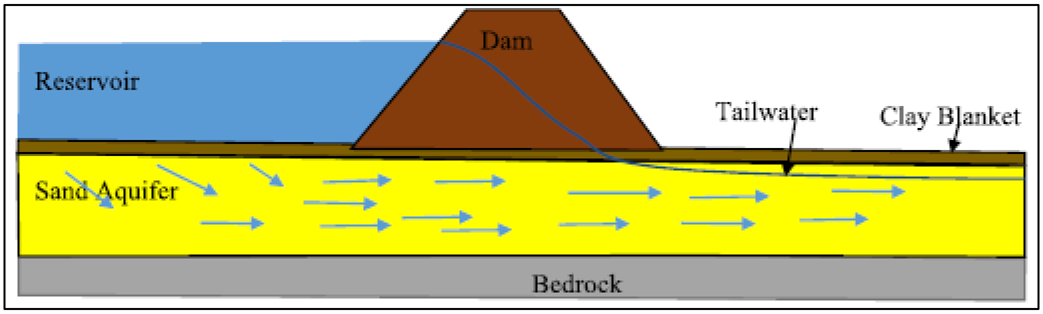

Figure 2: Seepage through a sand aquifer (Schaefer, O'Leary, & Robbins, 2017)

When the seepage force is high, sand particles are eroded and deposited in a conical ring. If erosion continues, it can ultimately lead to piping and dam failure. The seriousness of sand boil varies depending on the outflow. If there is clear water flowing out with no net increase, the boil is stable. Piezometers can be used to monitor downstream uplift pressure and help detect unsafe conditions. The sand boils can be classified into three types: (Training Aids for Dam Safety - Evaluation of Seepage Conditions, n.d.)

- **Type A** - The boil is stable and there is no further erosion, as per Figure 3.

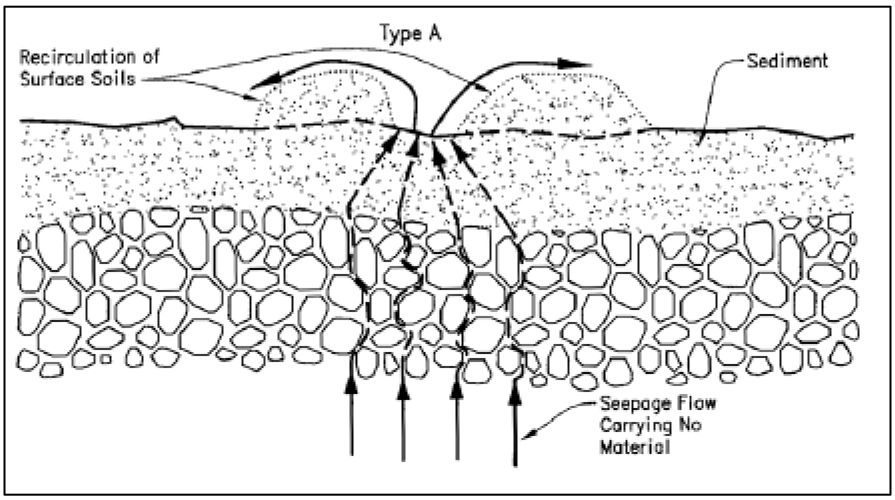

Figure 3: Type A Boil (Training Aids for Dam Safety - Evaluation of Seepage Conditions, n.d.)

- **Type B** - In the second type, erosion of the surface soil takes place and may indicate a potential problem. Figure 4 depicts a type B boil.

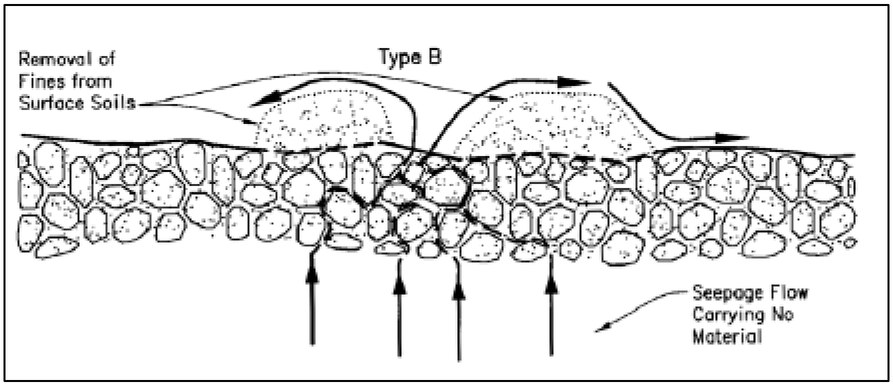

Figure 4: Type B Boil (Training Aids for Dam Safety - Evaluation of Seepage Conditions, n.d.)

- **Type C** - In the third type, internal erosion of the foundation layer is taking place and indicates a severe condition. The sand boil may increase in size, flow rate and muddy discharge. The dam can be in danger of failing, and it requires the immediate implementation of an emergency action plan. Figure 5 illustrates a type C boil.

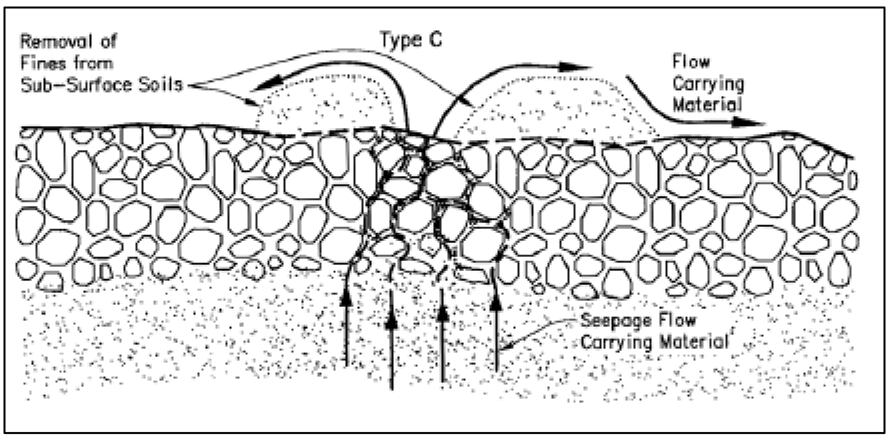

Figure 5: Type C Boil (Training Aids for Dam Safety - Evaluation of Seepage Conditions, n.d.)

<u>Modes of failure</u>

Sand eroding from boils can lead to dam failure if no erosion control is implemented. It is advisable to treat all boils with extreme caution even though not all of them will lead to dam failure. The failure mechanism can be classified in different stages as follows: (Van Beek, Bezuijen, & Sellmeijer, 2013) (Training Aids for Dam Safety - Evaluation of Seepage Conditions, n.d.)

1. **Seepage** - The first phase leading to failure. Seepage is common in all dams as water seeks a path of least resistance and can appear anywhere on the dam's downstream side.
2. **Backward erosion -** The absence of a filtered exit promotes backward erosion as the soil particles can be washed away. Backward erosion necessitates the fluidization of sand near the exit point. Fluidization is the process during which the sand expands and turns into a fluid state. The eroded particles are deposited in a ring outside the centre of the sand boil. This ring of deposited sand is often described as a sand volcano. As the erosion continues, more sand is deposited and the size of the cone increases.

3. **Widening** - As the pipe has developed across the entire base, linking the upstream and downstream sides, water flow increases significantly. The resulting flow has a higher velocity and erodes more soil particles, widening the pipe.
4. **Failure** - As the pipe widens, the flow velocity increases and causes more scouring. The dam structure loses its stability and may crack, deform, and heave, leading to dam failure.

Remedial Action: Emergency and Temporary Seepage Measures

Sand boils can threaten the safety and structural integrity of a dam. Unfixed boils can cause the foundation to erode and lead to a dam failure. Failure of a dam poses a significant flood risk to the downstream development. It can lead to the loss of life and costly damage to infrastructure. Emergency and temporary seepage measures that can be used include installation of a ring dike, or sand boil filter.

Ring Dike

The seepage exit can be controlled by building a sand dike or other ring dikes around the sand boil. The purpose of the ring is to raise the level of water at the surface of the boil to develop hydraulic backpressure decreasing the net head and upward flow of water and reducing loss of material. Ring dikes are usually constructed with sandbags. However, they can also be built with concrete well rings, short pieces of large diameter ring, earth berms and sheet piling. The height must be adjusted such that clear water exits. Water must keep flowing out of the dike to relieve the hydrostatic pressure in the ground. It prevents the formation of other boils in the neighbouring area. (Dam Owner Emergency Intervention Toolbox, 2016)

Constructing the sandbag dikes

- Size of dike: (Dam Owner Emergency Intervention Toolbox, 2016) - The size of the dike depends on the condition of the boil and must meet the following criteria:
    a. The height should be estimated such that clear water keeps flowing out.
    b. The inner ring of sandbags should be within 2-3 feet (0.6-0.9 metres) from the outer edge of the boil. The weak area of the boil must be within the dike.
    c. The base width of the dike must be 1.5 times greater than the estimated height.
    d. When there are a several boils, a single large dike should be built around the whole area.
- Prepping location and constructing the dike: (Dam Owner Emergency Intervention Toolbox, 2016)
    a. The base of the dike should be cleared of all debris and scarified to create a watertight bond between the ground and the sandbag.
    b. The bags should be two-thirds full and packed firmly in place.
    c. The bags should remain untied. The untied end must be placed toward the inside of the ring and folded under the bag.
    d. The dike can be sealed with polyethylene sheet to improve water tightness. The sheet must be anchored at the bottom of the barrier on both sides.
    e. A spillway should be constructed on the top of the ring to allow water to flow out.

The exit channel helps control the water level within the ring. It is vital to monitor the height of the water as it is a crucial factor in maintaining the flow rate through the boil. (Dam Owner Emergency Intervention Toolbox, 2016) Building a dike is a more labour-intensive and costly process compared to a sand boil filter. Figure 6 illustrates a ring dike.

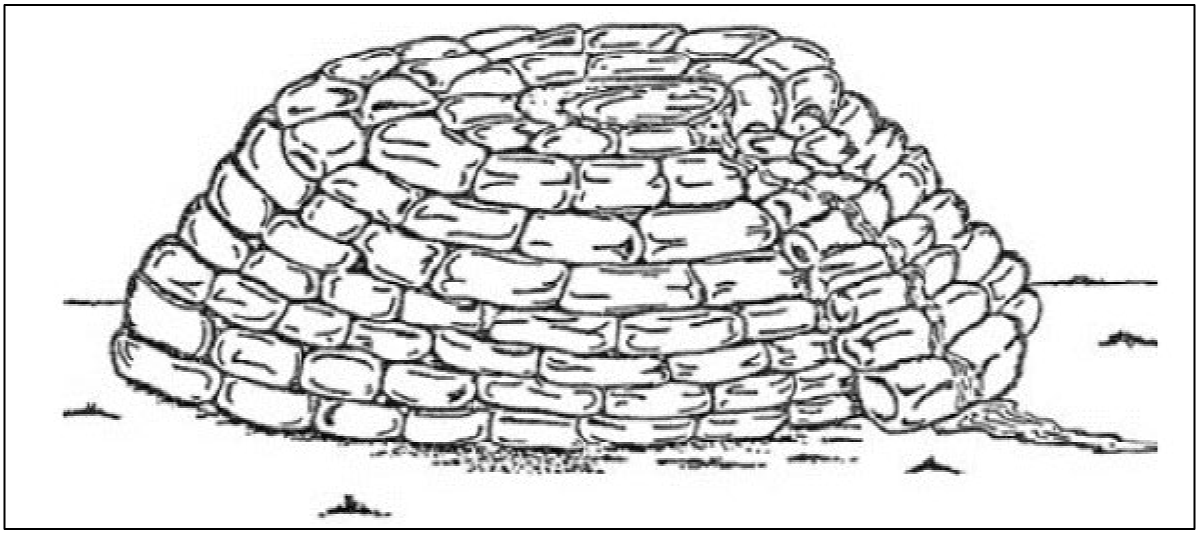

Figure 6: A ring dike around a sand boil (Dam Owner Emergency Intervention Toolbox, 2016)

When boils are located near the downstream slope of dams, they must be built as per Figure 7.

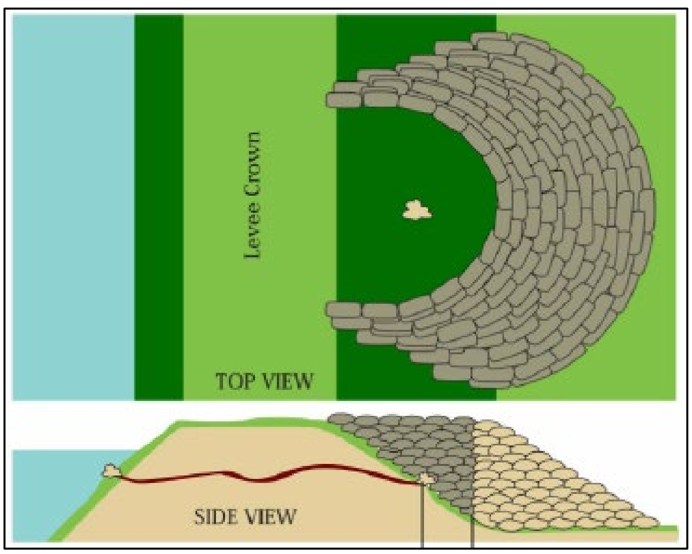

Figure 7: The dike is tied to the dam when the sand boil is close to the downstream slope of the dam. (Sandbagging Techniques, 2004)

Sand Boil Filter
A sand boil filter is a hollow, conical, and mesh type structure, as shown in Figure 8.

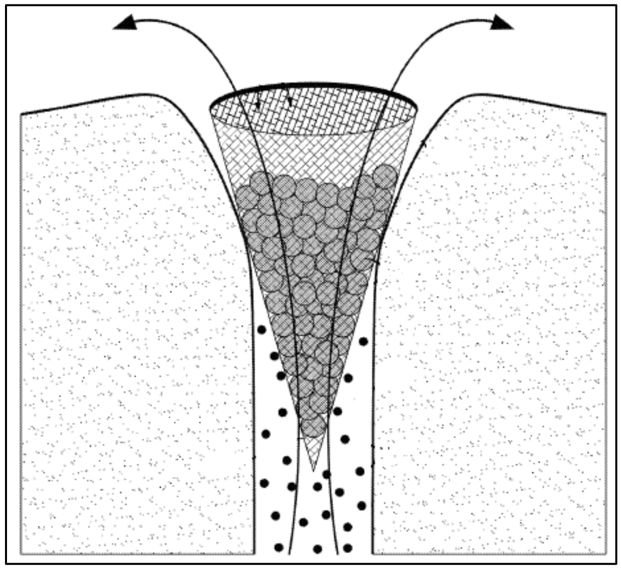

Figure 8: A sand boil filter (United States of America Patent No. US10,519,617 B2, 2019)

The filter is designed such that the mesh's size, number, and location allows water to flow while trapping sand particles. The cone is inserted in the sand boil, and gravels are placed within the hollow structure. The weight of the gravel balances the upward hydrostatic pressure and keeps the filter in place. The gravels also dissipate the flow energy. The filter prevents further internal erosion and growth of the sand boil. At the same time, it relieves the hydrostatic pressure in the ground and prevents the formation of other sand boils. Furthermore, the conical shape allows the filter to be used in various size sand boils. (United States of America Patent No. US10,519,617 B2, 2019)

Recommendation

1. The emergency action should be constantly monitored until permanent solutions are found. Standby personnel, equipment, and filter/drain material should be readily available if the boil shifts to a new location.
2. Abstain from placing sandbags directly over the boil. The pressure applied to plug the plug will cause a boil in another location.

References

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