TECHNICAL MEMO

Prepared By: Water Resources Management Division (WRMD)
Date: October 2023
Re: Emergency Response to Internal Erosion of Earthen Dam

Background

This memo is part of a series of documents on dam emergency interventions. Its focus is to provide guidance on internal erosion. Internal erosion, also known as piping, occurs when water seeps through an earthen embankment carrying soil particles away. As the seepage erodes the soil particle, a cavity or pipe is formed. The cavity starts to develop on the downstream side of the dam and erodes backwards to the reservoir. When the cavity reaches the reservoir, breaching occurs, resulting in dam failure. (Internal Erosion of Earth Dams, n.d.) Figure 1 illustrates the process of internal erosion.

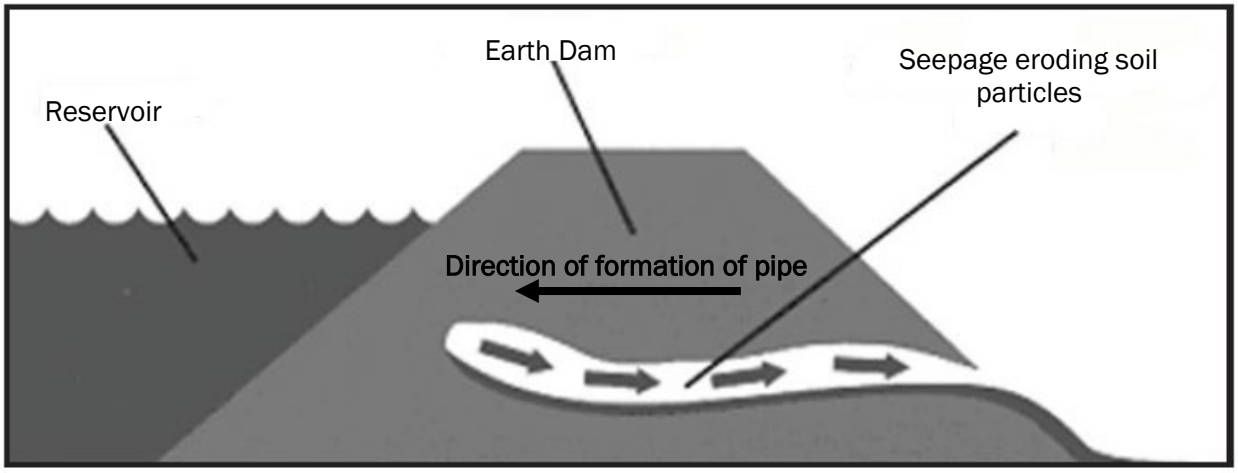

Figure 1: Internal Erosion taking place in an earthen embankment (Internal Erosion of Earth Dams, n.d.)

Internal erosion is among the most common causes of dam failures. Almost 30% of dam failures occur as a result of piping. (Saliba, Nassar, & Maalouf, 2019) Piping failure can take place when the reservoir is first filled or after years of operation. The satisfactory performance for many years does not guarantee that internal erosion will not take place. (Internal Erosion of Earth Dams, n.d.)

Internal erosion can be caused due to: (Internal Erosion of Earth Dams, n.d.)

1. High water surface elevation and pressure;
2. Outlet pipes buried in the embankment; and
3. Rodent activities.

Detection

Seepage is common in all dams as water seeks paths of least resistance through the embankment and its foundation. However, it must be controlled to prevent internal erosion and damage to structures. Seepage occurs anywhere on the downstream side and beyond the toe. Seepage can be a wet area or a stream of water. It may first appear as an area with lush and dark green vegetation, including cattails, reeds, and mosses. The presence of rust-colored bacteria also indicates seepage. (Seepage Through Earthen Dams, n.d.)

When the seepage force is high, it displaces soil particles and produces internal erosion. A dam can fail within a couple of hours after evidence of internal erosion is apparent. The signs can indicate a developing situation or imminent danger.

Signs of a developing situation: (Internal Erosion of Earth Dams, n.d.)

1. Water seeps out on the downstream side or within a few metres of an earthen dam. Sediment may also accumulate in that region.
2. Water flowing along the outside of the structure buried within the embankment, such as outlet pipe. Corrosion and deterioration of the structure also confirm the presence of water.
3. Water oozing near a dead or living tree.
4. Water flowing out of animal burrows.
5. The continuous drop in lake level.

Signs of imminent danger: (Internal Erosion of Earth Dams, n.d.)

1. There is a large flow of muddy water on the dam's downstream side next to the structure that penetrates the embankment.
2. The presence of sinkholes on the embankment.
3. Formation of a whirlpool on the lake surface.
4. The sudden drop in lake level.

The pictures included in Figure 2 illustrate internal erosion and failure of earthen dam.

Failure of dam due to internal erosion

Another dam failure due to internal erosion

Internal Erosion along concrete pipe

Sinkhole as a result of internal erosion

Figure 2: Dam failure due to internal erosion (Internal Erosion of Earth Dams, n.d.)

Monitoring

Regular monitoring is vital to detect seepage. It helps prevent a possible dam failure or provide enough time to implement an emergency response plan to limit the consequences of the dam failure. It is an excellent practice to record points of seepage exit, quantity and content of flow, size of the wet area, and type of vegetation. Photographs of seepage are also an invaluable piece of record and instruments such as a V-notch weir and piezometer can be used to monitor seepage. (Seepage Through Earthen Dams, n.d.)

It is crucial to monitor and maintain embankment and drainage outlets as well. The flow rate and flow content from each pipe outlet for toe drain, relief wells, weep holes, and relief drains should be recorded regularly. Maintenance includes clearing the pipes from obstructions. Pipe outlets should not be submerged for a long time as it prevents regular inspection and may cause pipe clogging. Knowing the dam's history, the inspector can determine whether the seepage is steady or changing. (Seepage Through Earthen Dams, n.d.)

Implementation of Emergency Action Plans (EAP)

Internal erosion threatens the safety and structural integrity of an embankment dam. 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. The Emergency Action Plans describe emergency actions that can prevent a possible dam failure or, at least, reduce the consequences of a failure. Planning and organizational measures help dam owners and local response personnel manage an emergency safely and effectively. (Technical Manual: Conduits through Embankment Dams, 2005) The table below is quoted from the "Technical Manual: Conduits through Embankment Dams." It consists of a list of potential problems due to seepage and internal erosion.

Table 1: Emergency Response Actions for seepage and internal erosion (Technical Manual: Conduits through Embankment Dams, 2005)

Problems or conditions	Cause	Response or emergency repair actions
Large increase in flow or sediment in seepage	A shortened seepage path or increased storage levels	• Accurately measure outflow quantity and determine amount of increase over previous flow rates. • Collect jar samples of the seepage to compare the turbidity of the water with time. • If either quantity or turbidity has increased by 25%, a qualified professional engineer should be engaged to inspect the conditions and recommend further corrective actions to be taken.
Internal erosion and backward erosion piping through the embankment dam, foundation or abutments	Water has created an open pathway, channel or pipe through the embankment dam. The seepage water is eroding and carrying embankment materials. Large amounts of water have accumulated on the downstream slope. Water and embankment materials are exiting at one point. Surface agitation may be causing the muddy water. A break in the conduit could be allowing water to discharge out of the conduit, in the case of a pressurized conduit beneath the embankment dam. A flow path has developed along the outside of the conduit.	• Begin monitoring the outflow quantity and establishing whether water is getting muddier, staying the same, or clearing up. • If the quantity of flow is increasing, the reservoir should be lowered until the flow stabilizes or stops. • Search for a possible opening on the upstream side of the embankment dam and plug, if possible, with available materials such as hay bales, bentonite, or plastic sheeting. • Place a protective filter of sand and gravel over the exit point(s) to prevent further migration of fine embankment materials • Continue operating the reservoir at a reduced reservoir level until repairs can be made. • Engage a qualified professional engineer to inspect the conditions and recommend further corrective actions to be taken.
Sinkholes	Backward erosion piping of embankment materials or foundation causes a sinkhole. A sinkhole can develop when a subterranean erosion feature collapses. A small hole in the wall of a conduit can allow backward erosion piping of materials	• Inspect other parts of the dam for seepage or more sinkholes. • Identify actual cause of the sinkhole(s). • Check seepage and leakage outflows for dirty/muddy water. • Carefully inspect and record location and dimensions (depth, width, length) of the sinkhole. Stake out the sinkhole to monitor

	and develop a sinkhole. Dirty water at the exit portal indicates erosion of the embankment dam materials.	any growth and development of the sinkhole. Frequent monitoring of sinkholes and seepage. • Lower the reservoir level to a safe level or until the seepage stops. If the sinkhole results from backward erosion piping of embankment materials into the conduit, alternative means to evacuate the reservoir may be required, such as siphoning, pumping or controlled breach. • Excavate the sinkhole and plug the flow with whatever material is available (e.g., hay bales, bentonite, or plastic sheeting), if the entrance to the internal erosion can be located. • Place a protective filter of sand and gravel over the exit point(s) to prevent further migration of fine embankment materials. • Engage a qualified professional engineer to inspect the conditions and recommend further corrective actions to be taken.
Excessive settlement of the embankment or dam crest	Lack of or loss of strength of embankment materials. Loss of strength can be attributed to: • Internal erosion or backward erosion piping of the embankment dam materials along the conduit. • Infiltration of water into the embankment materials from a crack in the conduit	• Establish monuments along length of crest and selected locations on the embankment dam to determine exact amount, location, and extent of the settlement. • Engage a qualified professional engineer to determine the cause of the settlement and to supervise all steps necessary to reduce possible threat to the dam and correct the condition. • Re-establish lost freeboard, if required, by placing sandbags or backfilling in the top of the slide with suitable embankment materials. Caution should be exercised not to further increase slide potential. • Re-establish monuments across the crest and selected locations on the embankment dam and monitor monuments on a routine basis to detect possible future settlement. • If continued movement of the settlement of the embankment dam is seen, begin lowering the reservoir at a rate and to an elevation considered safe given the settlement condition. • Continue operating the reservoir at a reduced reservoir level until repairs can be made.

Other Considerations

Initial repair of sinkholes

Sinkholes on the embankment surface are formed as a result of erosion of the embankment material. The sinkhole is usually an indicator of a larger cavity beneath the surface. It is a severe problem that requires the immediate implementation of the emergency action plan. (Technical Manual: Conduits through Embankment Dams, 2005)

Repair of sinkholes is required to stabilize the dam and is achieved by placing a well-graded sand and gravel mix with non-plastic fines into the sinkhole. The sand and gravel will filter the embankment core material and cause a seal to form, stopping the erosion. It is only a temporary solution and the sinkhole must be investigated by dam engineers to determine a long-term solution. (Technical Manual: Conduits through Embankment Dams, 2005)

Alternative means to drawdown a reservoir

Alternative methods to lower the reservoir level need to be implemented if the outlets are not functioning correctly or the outlet capacity is inadequate. The selection of the method depends on the size of the reservoir, physical features of the dam, availability of materials, volume of water that need to be released. The drawdown method should be implemented carefully to prevent loss of life and damage to properties downstream of the dam. The methods include: (Technical Manual: Conduits through Embankment Dams, 2005)

- Siphoning and pumping - Siphoning and pumping are the two most common types of emergency drawdown methods. It is elaborated in the Technical Memo titled "Reservoir drawdown".
- Controlled breach of the dam - This method is implemented only when the water level is threatening the integrity of the dam. The purpose is to prevent complete failure of the dam or reduce the consequences of dam failure. The process is further described in the memo titled "Controlled Breach of Earthen Dams".

Recommendations

The memo advocates actions that serve only as a guide. An experienced dam engineer or geotechnical engineer must choose the appropriate course of action based on the site conditions in the event of an emergency.

References

Internal Erosion of Earth Dams. (n.d.). Retrieved from Association of State Dam Safety Officials: https://damsafety.org/dam-owners/internal-erosion-of-earth-dams

Saliba, F., Nassar, R. B., & Maalouf, Y. (2019). Internal Erosion and Piping Evolution in Earth Dams Using an Iterative Approach. *Eighth International Conference on Case Histories in Geotechnical Engineering* (pp. 67-75). Lebanon: American Society of Civil Engineers.

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