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RISK CONTROL PRACTICE: SPECIAL HAZARDS

Embankment and tailing Dams Handbook

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This Handbook | Guidance Note has been prepared to identify and flag issues a prudent Underwriter and Risk Engineer ought to consider and evaluate relating to industries involving Embankment Dams - risk selection, determination and calculation of loss estimates - when determining whether to accept a risk and, if so, on what terms.

Although this Handbook | Guidance is detailed and deals with a number of hazards, it is not intended to be a comprehensive analysis of every peril and potential scenario an underwriter may be requested to provide cover for. Any estimation or projection of an MPL and final loss amount must be based on reliable, accurate and current values, applicable scenarios, and consideration of the relevant perils. SCOR accepts no responsibility or liability for any use of this handbook by any party in order to underwrite any particular risk or to determine a Loss Estimate or final loss amount – it is the responsibility of the relevant underwriter and (re)insurer to independently determine whether to accept, or not, any particular risk and the contract terms and price to be required.

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SCOPE

The purpose of this Handbook | Guidance Note is to provide basic comprehensive technical support to underwriters and risk control engineers when dealing with Embankment Dams used to retain water or effluents, or to protect ground exposure from any higher body of water (e.g. including streams, rivers and other waterways, lakes, wetlands, reservoirs, and creeks).

The specific case of tailings dams, which are used to store by-products during mining operations (such as in the mining industry or metal industry), is not discussed in this document. See dedicated Handbook “Tailing & Tailing Management Facility (TMF)”.

The structure of Embankment Dams and related special hazards is described. Standard recommendations based on recognized international standards and good practices are proposed.

This special hazard guide was implemented with:

- Franck Orset (FPO) – Loss Prevention Engineer for Nuclear Risks and former HPR working in insurance.
- Amanda Langer - Global Practice Leader for Construction Claims at SCOR Services UK Limited.
- Tim Chapman - Regional Construction Manager for EMEA at SCOR Services UK Limited.

Many thanks to them for their invaluable and extensive contribution.

I - OVERVIEW & RISK

Embankment Dams can be found in various occupancies that are large consumers of water (e.g. water supply & networks, processes and cooling water for the pulp & paper industry or power plants including nuclear). Embankment Dams can also be used for the retention of effluent or as an emergency basin in various industries. Embankment Dams (also known as 'levees') can be found in various areas and are used to protect facilities from being flooded by the nearest body of water on higher ground. Embankment Dam structures are mostly earth dam structures as discussed in this document.

1. STRUCTURE

Courtesy of Franck Orset (FPO) – Loss Prevention Engineer for Nuclear Risks and former HPR.

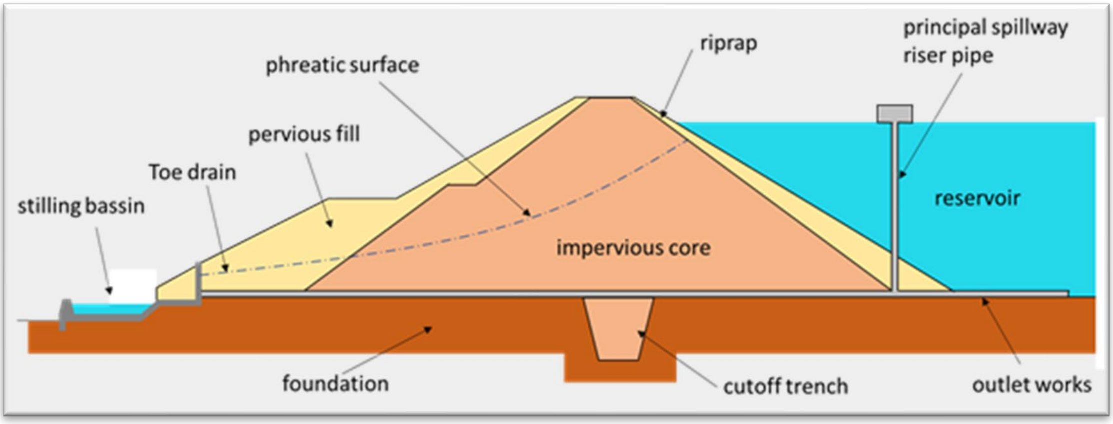
An embankment dam is a large artificial dam. Dams are constructed of excavated earth materials, such as sand gravels or soils. It is typically created by the placement and compaction of a complex semi-plastic mound of various compositions of soil, sand, clay, or rock.

Normally, embankment dams are built up on nearly all types of soil. The design is significantly impacted by the characteristics of the soil upon which the dam is built up. They rely on their heavy weight to resist the force of water (and they are armed with a dense waterproof core to prevent water from seeping through the structure).

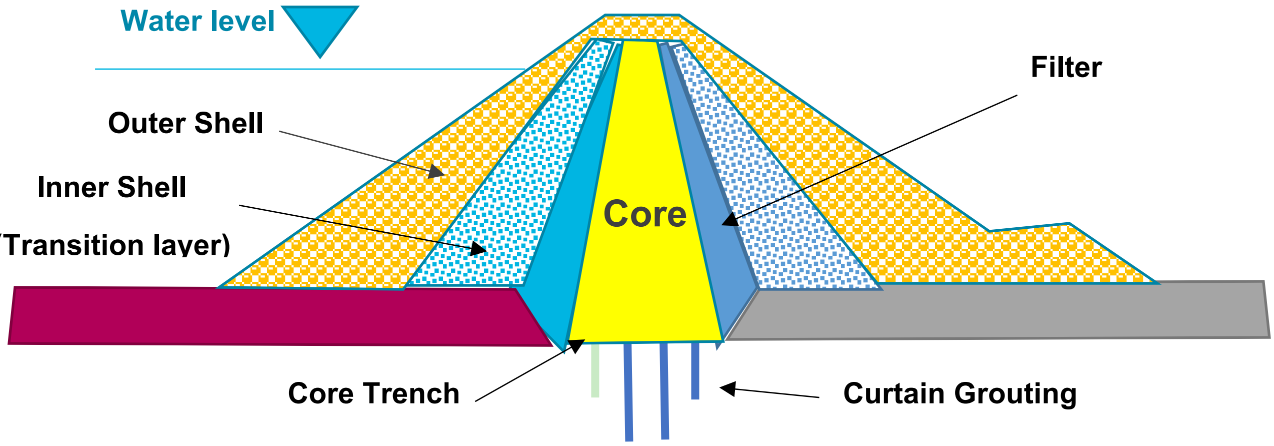
This dam type is a good choice for sites with wide valleys. It can be built on hard rock or softer soils. For a rock-fill dam, rock-fill is blasted using explosives to break the rock. Additionally, the rock pieces may need to be crushed into smaller grades to get the right range of size for use in an embankment dam. Material is filled or placed to create a dam with slopes on both sides (upstream and downstream dam faces)

The dam has a semi-pervious waterproof natural covering for its surface and a dense, impervious core which renders it impervious to surface or seepage erosion. Such a dam is composed of fragmented independent material particles. The friction and interaction of particles binds the particles together into a stable mass rather than having to use a cementing substance.

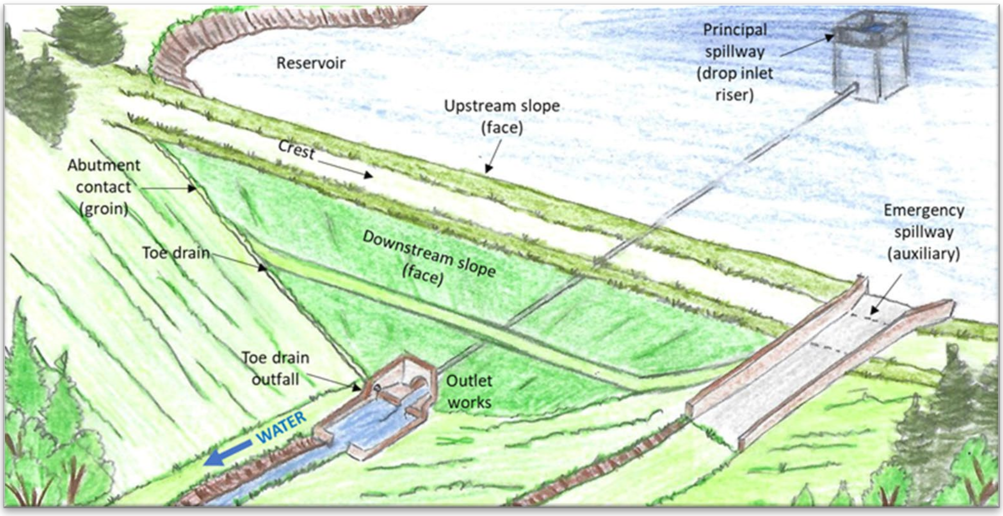
A cross-section of an embankment dam shows a shape like a bank, or hill. Most have a central section or core composed of an impermeable material to stop water from seeping through the dam. The core can be of clay, concrete, or asphalt concrete. Variations may include rock, earth, rolled earth or hydraulically placed fill.



Components of a typical earthen dam – cross section
© Franck Orset (FPO)



Typical embankment dam structure - inner cross section details
© Didier Schütz (DLS)



Components of a typical earthen dam - overview
© Franck Orset (FPO)

Moroccan storage pond, near Agadir.

Aerial view of the water reservoire Dlouhe Strane in Jeseniky mountains, Czech Republic,

2. EARTHQUAKE EXPOSURE

Because the foundations of concrete dams are typically keyed into bedrock, concrete dams do not usually experience great accelerations when shaken by earthquakes. For this reason, concrete dams have achieved an excellent safety record in terms of withstanding seismic forces.

The safety record for embankment dams is also good, with the notable exception of earth fill dams constructed using hydraulic fill technology. Such dams retain a large quantity of water within their soil structure, which renders them vulnerable to liquefaction of the saturated soil when hit by a seismic shock.

Earthquake loadings may lead to several damaging circumstances in the performance of a dam. Liquefaction, where an embankment or foundation loses shear strength when subject to shaking, may

cause sliding, blockage, or rotational failures leading to excessive settlement and loss of freeboard ultimately resulting in an overtopping failure.
Overtopping may also be caused by slope failures or rock falls that enter the reservoir basin, displacing a large volume of water. A seiche, or earthquake induced wave, may also overtop and damage the structure. Fault ruptures may trigger differential settlement and cracking of a dam leading to internal erosion and enlargement of cracks until failure ultimately results. During earthquakes, shaking abutments and foundations may shift and move allowing the dam to tilt, rotate, or slide and lose its structural integrity.

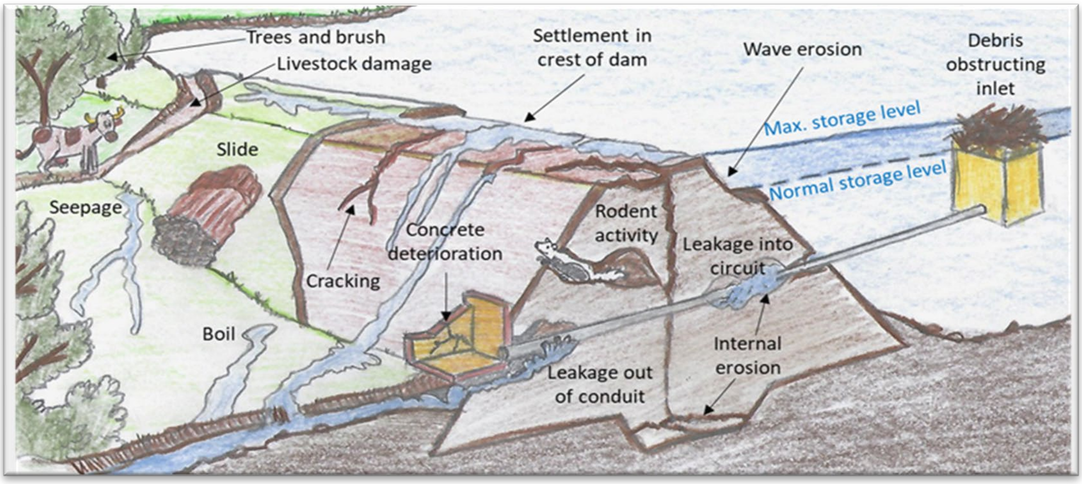
Slope failures on or near the dam may cause the reservoir to overtop the dam. Material failure may block spillways and outlets. Often the failure of a dam under a seismic loading is attributed to a combination or sequence of the above circumstances.

Large artificial reservoirs may also trigger earthquakes that would not occur in the absence of the reservoirs. Reservoir-induced earthquakes may be caused by the extra weight of the water or, more typically, by increases in the groundwater pore pressure reducing the strength of the rock beneath the reservoir. These tremors are usually not large, but they can cause minor damage to communities in the region surrounding the dam.

3. CAUSE OF FAILURES

The rate of dam failures has decreased over the years. According to studies carried out by the International Commission of Large Dams (ICOLD) and the United States Commission of Large Dams (USCOLD), embankment dams built in the 1900s have a probability of failure of 10%, while those built in the 1930s have a probability of failure of 1% and modern dams (constructed after 1950) have a less than 0.04% probability of failure.

Dams over 30 years old have a significantly higher risk of failing than do modern dams. Older embankment dams have a higher risk of failure than do concrete types.
Dams that have been in service for an extended length of time are not immune to failure. Some failures may take years to develop.



Various causes of failures of earthen dam structures. © Franck Orset (FPO)

Major causes of failures are the following:

- Overtopping: Overtopping of a dam is often a precursor to dam failure. The principal reason for overtopping is an inadequate spillway capacity.
- Earth embankments are not designed to be overtopped and therefore are particularly susceptible to erosion. Once erosion has begun during overtopping, it is almost impossible to stop.
- Overtopping of concrete dams and masonry dams does not necessarily cause failure.

- Overtopping due to inadequate spillway design, debris blockage of spillways, or settlement of the dam crest accounts for approximately 34% of all US dam failures.
- Water seepage, leakage or internal channeling (piping) of embankment dams: Water seepage is the principal cause of failure in embankment-type dams.
- Every embankment dam has water passing through or under the embankment because all earth materials are porous. The passage of water through or under the embankment is known as seepage. Seepage quantities and rates increase as the depth of the water in the reservoir increases due to greater pressure upstream of the embankment.
- Piping is when seepage through a dam is not properly filtered and soil particles continue to progress, and form sink holes in the dam. Erosion of the soil begins on the downstream side of the embankment, either in the dam proper or the foundation, progressively working its way toward the reservoir.
- Seepage often occurs around hydraulic structures, such as pipes and spillways, through animal burrows, around roots of woody vegetation and through cracks in dams, dam appurtenances and dam foundations.
- 20% of US dam failures have been caused by piping (internal erosion caused by seepage).
- Water leakage, seepage, internal channeling and erosion are indicated by wet spots, boils or other evidence of pressure flow, leaching, channelization and gully formation, sinkholes, soft spots, local settling, marsh-type vegetation and unexplained soil loss.
- Piping action can be recognized by an increased seepage flow rate, the discharge of muddy or discolored water, sinkholes on or near the embankment and a whirlpool in the reservoir.
- Heavy drainage can be caused by cracked, deteriorated or porous concrete, leaking tunnels and penstocks or internal sediment washout and channeling.
- Foundation seepage, leakage or internal channeling: This is more problematic with embankment-type dams than concrete gravity-type dams.
- Foundation defects, including settlement and slope instability, cause about 30% of all dam failures in the US.
- Pool stage changes, whirlpooling, depressions and sinkholes in the basin surface suggest heavy drainage or channeling in the reservoir foundation.
- Channel erosion: In most cases, spillways failed in embankment dams. Other cases involved the washout of various structures or undermining of dams.
- Sliding: Sliding is related to instability in the foundations, embankments or abutments.
- Leaning trees, hillside distortions, escarpments, pool encroachment, silting, channel approach obstructions and bank wetness suggest landslide potential.
- Other failures are due to deformation, deterioration, faulty design or construction, gate failures or other miscellaneous causes.
- Structural failures can occur in either the embankment or the appurtenances. Structural failure of a spillway, lake drain, or other appurtenances may lead to failure of the embankment. Cracking, settlement and slides are the more common signs of structural failure of embankments.
- Minor defects such as cracks in the embankment may be the first visual sign of a major problem which could lead to failure of the structure.

4. SPECIFIC IMPACT OF PLANTS ON EARTHEN DAMS

Tree and woody vegetation penetrations of earthen dams and their appurtenances have been demonstrated to be causes of serious structural deterioration and distress that can result in failure of earthen dams. When trees and woody plants are allowed to grow on earthen dams, they can hinder safety inspections, can interfere with safe operations or can even cause dam failure. However, a healthy, dense stand of low-growing grass on earthen dams is a desirable condition and should be encouraged.

Dam safety problems caused by woody vegetation growth are:

- Uprooted trees that produce large voids and reduced freeboard and/or a reduced x-section for maintaining stability
- Decaying roots that create seepage paths and internal erosion problems
- Trees, woody vegetation, briars and vines which interfere with effective dam safety monitoring, inspection and maintenance for seepage, cracking, sinkholes, slumping, settlement, deflection and other signs of stress
- Hindering desirable vegetative cover and causing embankment erosion
- Obstructing emergency spillway capacity
- Falling trees causing possible damage to spillways and outlet facilities
- Clogging embankment underdrain systems
- Cracking, uplifting or displacing concrete structures and other facilities
- Inducing local turbulence and scouring around trees in emergency spillways and during overtopping
- Providing cover for burrowing animals
- Loosening compacted soil
- Allowing roots to wedge in open joints and cracks in foundation rock along abutment groins and toes of the embankment, thus increasing piping and leakage potential
- Root penetration of conduit joints and joints in concrete structures

Consequently:

- Existing trees should be removed and not be allowed to mature on earthen dams, abutment groins, or around water conveyance structures
- Trees or shrubbery should never be planted on or around new or existing dams
- Existing trees should be watched closely until they are removed
- Grass and shallow-rooted native vegetation are the most desirable surface covering for an earthen dam.

There are potentially hazardous tree conditions such as decaying or dead branches, lightning-caused splits, stripping or breakage, leaning, uprooted or blown-down trees and seepage around exposed tree roots located along embankment slopes, especially in vulnerable downstream toes or abutment areas. Outward leaning trees may result from a slumping embankment condition that can be an indicator of slope instability.

Woody vegetation and tree growth creating undesirable root penetrations in earthen dams can be controlled or prevented by proper management of root growth into new dams and dams that have previously been cleared of trees by proper removal procedures.

Densely compacted soils discourage root elongation through increased resistance, lowered oxygen levels and reduced available water.

Soil compaction specifications generally require that compaction moisture contents be maintained at around 2% below to 3% above optimum moisture content. At these degrees of compaction and at these moisture contents, soil oxygen content, water content and soil pore size are unsuitable for healthy root elongation and tree growth. Consequently, the compacted dam embankment fill soil produces an exclusion system that mechanically impedes healthy root elongation and tree growth.

5. RODENT CONTROL

Rodents such as the groundhog (woodchuck), muskrat and beaver are attracted to dams and reservoirs and can be quite dangerous to the structural integrity and proper performance of the embankment and spillway.

Groundhog and muskrat burrows weaken the embankment and can serve as pathways for seepage.
Beavers may plug the spillway and raise the pool level.
Rodent control is essential in preserving a well-maintained dam.
Damage from animal intrusions can occur throughout the dam. The damage can include removal of surface vegetation, rutting and burrowing.

6. FAILURE MECHANISMS AND POSSIBLE REMEDIATIONS

When a dam develops a defect, it often takes very little time before that defect evolves into a full-scale failure mechanism and threatens complete breaching of the dam structure.

Possible changes in physical conditions that are indicators of mechanism failure are increased pore pressures, increased seepages, heavy drainage, piping (internal channeling), bank erosion, soil saturation, land sliding, settlement, vertical tilting or other displacements and undermining of the dam or associated structures, foundations or reservoir.

Concrete deterioration is significant for concrete constructions. Soil saturation is particularly important in the reservoir banks and perimeter slopes where wave action or unstable slopes can cause slumping, land sliding and sedimentation. There are five essential steps involved in any emergency reaction to a dam crisis:

6.1. Preparation

Preparing for various potential failure modes before warning signs are even observed is a key factor for success. Time is a crucial element during a dam failure emergency and planning ahead is the best way to attenuate the dam repair procedure. As-built drawings, operations and maintenance manuals and inspection reports should be recorded and kept up-to-date. Detailed instructions should be indicated in the Emergency Action Plan. For earth dam structures, stockpiling gravel, sand and other remedial materials on-site can be another important step to minimizing the time between identifying the problem and beginning to work on a solution. This would allow materials to be applied directly to the dam when needed and eliminates the possibility of not being able to obtain the needed resources in time to fix the problem.

6.2. Assessment

The problem needs to be thoroughly assessed in order to determine exactly what type of crisis is occurring. The mode of failure, progression of the defect and potential threats should be determined quickly and accurately. Correct procedures outlined in the Emergency Action Plan should then be followed accordingly. It is also crucial to establish baseline conditions pertaining to the failure mode, as well as a way to measure their progression on a regular basis. Marking levels where sloughing occurs, installing weirs to measure seepage, and collecting readings from observation wells are examples of monitoring the conditions conducive to various failure modes.

6.3. Monitoring

Regular monitoring of conditions at the dam should be established and the results documented. Visual, in-person inspection is essential. Good descriptions, data recordings and photos should be taken and kept for analysis. When issues are identified, repair-oriented actions should be taken to try to fix the problem before it develops. If conditions are noticed as worsening, emergency intervention options should be analyzed and implemented as soon as possible. Tilt meters, strain meters, piezometers, seismometers and weirs are common devices used for monitoring the dynamic structural behavior of a hydraulic structure.

6.4. Response

An appropriate response should be chosen and enacted whenever considered necessary based on observations and monitoring. Sometimes damaging the dam structure will be the safest response, as in the case of a controlled breach. In almost all cases, reservoir drawdown processes should be commenced as soon as possible to try to relieve the hydraulic loads acting on the dam. If the condition of the dam is judged to be significantly deteriorating, emergency actions should be taken. Actions such as using sandbags to increase freeboard and prevent overtopping, using riprap to prevent erosion of the dam structure, or applying a geotextile filter fabric to combat piping are all examples of emergency intervention techniques that can be used to try to save a dam from total failure.

6.5. Post-Action Documentation and Follow-Up

After the emergency situation has been resolved, documentation of the situation and actions taken should be drafted as soon as possible. This should contain the conditions observed and any responses made throughout the entire emergency timeline. It should also be as descriptive as possible and contain pictures, sketches and any relevant measurements or data taken. The report should also recommend any further actions, if deemed necessary. These could include inspections or further repairs to the structure.

II - EMBANKMENT DAM SURVEYANCE

Courtesy of Franck Orset (FPO) – Loss Prevention Engineer for Nuclear Risks and former HPR.

1. NEED FOR A PROPER EVALUATION

The need for a proper evaluation of the good condition of the structural integrity of dams is essential to avoid a potential collapse of the dam that could result in the possible flooding of the entire facility, (in particular in the case of earth movements such as earthquakes), or in possible upstream flooding events that could overflow the reservoir capacity.

Local regulations should be strictly adhered to for dam inspections, in particular when dams may represent a threat to neighboring activities/communities in case of breakage. It is the responsibility of the owner of the dam to operate and maintain the dam and all appurtenant works in safe conditions at all times

Depending on the location of the risk the owner should be aware that they may face exposure to claims from third parties in the event of a breach and should take appropriate steps to ensure the necessary insurance protection is in place.

As dams continue to age, they may not be able to safely withstand natural events such as large floods and earthquakes. Their outlets and spillways may be severely eroded (to the extent that they threaten the safety of the dam and their foundations) and embankments are much more likely to develop seepage or stability deficiencies.

The following areas need to be carefully surveyed:

- The dam
- The spillways and outlet works
- Other appurtenant structures
- Embankments
- The reservoir rim
- The reservoir operations

2. CONTINUOUS SUPERVISION

A dam safety inspection is the first step in preventive maintenance. The inspection may reveal that there are no issues with the dam or else reveal obvious deficiencies or even a potential change in hazard classification.

Dam safety inspections should include but are not limited to a review of previous inspections, reports and drawings; an on-site inspection of the dam, seepage control and measurement system, voids, soil displacement, excessive vegetation, damage to the outlet works and spillway, cracking and general erosion; and an evaluation of data from permanent monuments or monitoring installations, if any. The inspection should include an assessment of all parts of the dam which are related to the dam's safety.

The owner is responsible for regularly checking the dam (unless prohibited by weather or difficulty of access to the dam), especially at times when the reservoir is full, during heavy rains or flooding and following an earthquake.

There are 3 possible ways to regularly check dams:

- A visual examination, in particular to check for possible water leakage, should be done at least once a week.
- Monitoring by permanently installed instruments or instruments used by plant personnel for quick checks for seepage, horizontal and vertical movement (piezometers, etc.)
- Data that should be collected on a monthly basis
- More complex monitoring (such as topographic measurements) with the intervention of dam specialists. This data should be collected on a 6-monthly basis.

Any deviation should immediately be analysed and appropriate action to remediate the issue should be taken. Particular care should be taken during the first filling of the dam. The water level should be raised by steps and the dam behaviour (as well as the direct environment of the dam) should be carefully analysed at each step.

3. PERIODIC INSPECTION

A full check of the dam should be carried out on a regular basis, first after 5 years of operation, and then every 10 years, by emptying the water reservoir in order to check the immerged part of the dam structural elements.

4. SPECIAL INSPECTION

A special inspection is conducted when only a particular feature of a dam is to be inspected. Often, a unique opportunity might present itself to inspect this feature which is otherwise not easily done. For example, if an upstream slope is to be unwatered, an inspection of that slope could be scheduled. Or, if scuba divers are needed to inspect features generally under water, that inspection could be scheduled as a special inspection.

5. EMERGENCY INSPECTION

An emergency inspection is performed when the immediate safety of the dam is of concern, or in the event of unusual or potentially adverse conditions at the dam (e.g., during a large flood or immediately following an earthquake).

III - EMBANKMENT DAM GENERAL MAINTENANCE

Courtesy of Franck Orset (FPO) – Loss Prevention Engineer for Nuclear Risks and former HPR.

1. MAINTENANCE AND REPAIR ACTIVITIES

General maintenance and ordinary repairs that do not impair the safety of the dam should be regularly performed.
These maintenance and repair activities include:

- Removal of brush or tall weeds.
- Cutting of trees and removal of slash from the embankment or spillway: Removal of small stumps is acceptable provided no excavation of more than 3 feet (1 m) into the embankment occurs. An engineer must oversee the removal of trees and stumps larger than 12” (30 cm) in diameter.
- Rodent control, removal or extermination: Repair of minor rodent damage is acceptable provided it does not involve excavation of more than 3 feet (1 m) into the embankment.
- Repair of erosion gullies on the embankment or in the spillway: Large gullies that have already weakened the dam must be repaired.
- Surface grading of the embankment crest or spillway to eliminate potholes and provide proper drainage provided that the freeboard is not reduced: Material placed on the dam crest to restore the design freeboard must be compacted. Placement of material in excess of 1 foot (30 cm) in depth to provide freeboard is not considered general maintenance.
- Placement of additional riprap and bedding on the upstream slope, or in areas of the spillway that have sustained minor damage: Such placement shall be limited to restoring the original riprap protection where the damage has not yet resulted in the weakening of the dam.
- An engineer must oversee restoration of the embankment.
- Painting or caulking metal structures or lubricating mechanical equipment.
- Patching, sealing or caulking spalled or cracked concrete surfaces to prevent deterioration.
- Removing debris, rock or earth from outlet conduits, outlet channels or spillway channels.
- Patching or sealing surface damage to prevent further deterioration within outlet conduits.
- Replacement of worn or damaged parts of outlet valves or controls for restoration to their original condition.
- Repair or replacement of fences intended to keep traffic or livestock off the dam or spillway.
- Landscaping of new and existing dams and spillway channels is not general maintenance. No trees or large vegetation shall be planted within 25 feet (7.5 m) of the footprint of the dam.

2. EMERGENCY ACTIONS

Emergency actions that do not impair the safety of the dam may be taken immediately but are considered as interim solutions only and may not serve as a permanent solution to the problem being addressed. Additional remedial actions may be required after the emergency passes. Emergency actions may include:

- Stockpiling materials such as riprap, earthfill, sand, sandbags and plastic sheeting
- Lowering the reservoir level by carrying out controlled releases through the outlet or a gated spillway, by pumping or by siphoning
- Armoring eroding areas by placing sandbags, riprap, plastic sheeting or other available material
- Plugging leakage entrances on the upstream slope
- Increasing freeboard by placing sandbags or temporary earthfill on the dam
- Diverting flood waters around the reservoir or closing inflow diversions
- Constructing training berms to control flood waters
- Placing sandbag ring dikes around boils at the downstream toe to provide back pressure and/or
- Removing obstructions from outlets or spillway flow areas.

Lowering the water level by excavating the spillway or embankment is prohibited unless failure is imminent.

IV - TECHNICAL REFERENCES

The following documents were consulted for this study:

- Technical Manual for Impacts of Plants on Earthen Dams – FEMA 534 – September 2005 (https://www.fema.gov/media-library-data/20130726-1446-20490-2338/fema-534.pdf)
- Indiana Dam Safety Inspection Manual – Part 5 – Dam Safety fact Sheets (https://www.in.gov/dnr/water/3593.htm)
- Causes of failures of Earthfill dams (https://theconstructor.org/water-resources/causes-failures-earthfill-dams/2287/)
- Lessons Learned from Dam Incidents and Failures (https://damfailures.org/lessons-learned/)
- E.6 Colorado – FEMA.gov / State of Colorado Department of Natural Resources – Division of Water Resources – Dam Safety Branch / Rules and Regulations for Dam Safety and Dam Construction - https://www.fema.gov/media-library-data/20130726-1849-25045-4809/14_hydrosafetydam_app_e.6_e.8.pdf

This list is not exhaustive.

Other publications in this series:

- RISK CONTROL PRACTICE: CONSTRUCTION MATERIAL
  Wall Assembly Classification Handbook
- RISK CONTROL PRACTICE: EXPOSURE
  Falling Aircraft Handbook

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