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Introduction to Visual Inspection Of Earthfill Dams

By:

Dana Cork, Civil Engineer/Dam Safety Coordinator, U.S. Bureau of Land Management

Todd H. Hill, Chief, Safety of Dams Branch, U.S. Bureau of Reclamation

Atiq Syed, Program Manager Dams and Water Resources Engineering, U.S. Forest Service

Pham Ngoc Quy, Water resources University, Hanoi, Vietnam

Nguyen Manh Hung, Vietnamese expert

Nguyen Dinh Thanh, Vietnamese expert

Dong Van Tu, Director of Hydraulic work management and Dam Safety, Directorate of Water resources.

Cam Thi Lan Huong, Department of Science, Technology and International Cooperation, Directorate of Water resources.

Doan Thị Tuyết Nga, Deputy Director, Department of Science, Technology and International Cooperation, Directorate of Water resources.

Nguyễn Thị Xuân Hồng, Department of Science, Technology and International Cooperation, Directorate of Water resources

Nguyen Thi Quynh Giao, Department of Science, Technology and International Cooperation, Directorate of Water resources.

Do Thi Phuong Thao, Department of Science, Technology and International Cooperation, Directorate of Water resources.

BACKGROUND

Earthfill dams are one of the most popular water resources structures in the world and in Vietnam. Therefore, it is required that these structures must be operated effectively and safe for key dam's features, to ensure safety of downstream areas, beneficiary areas and related areas.

To ensure safe and effective dam operation, all stages should be performed synchronously and accurately during the process of surveying, design, construction and operation. Those processes have been developed in different periods with various starting condition. Thus, the situtation of reservoirs in Vietnam varies by areas. Moreover, the climate change have brought new challenges and obstacles for ensuring dam safety

During opeartion and management, reservoir operators collect data of rainfall, flood, earthquake, seepage, deformation, damage, etc. Visual inspection is one of the methods to collect such data.

"Introduction to visual inspection of earthfill dam" is the publication which is translated, printed and issued in the framework of the Smart Infrastructure for the Mekong (SIM) program. The purpose is to provide techinal assisstance for Directorate of Water Resources, Ministry of Agriculture and Rural Development of Vietnam in improving safety and climate resilience for small and medium reservoirs under the supervison scope of the project. The assistance includes two Train-the-Trainer's workshops and the development of a standard earth dam inspection handbook (visual inspection) that will allow the Ministry of agriculture and rural development to transfer inspection and safety assessment knowledge to provincial, municipal, and private reservoir operators across the nation

I. INTRODUCTION

1.1 Purpose of Dam Inspections and Role of On-Site Personnel

a) The main purposes for performing visual inspections

The main purposes for performing visual inspections are to identify conditions:

1. that pose an immediate threat to the ability of the structure to safely store water;and
2. that could, through further deterioration threaten the safety or operability of the structure in the future.

Another purpose for a dam inspection is to ensure that the appurtenant features will be able to perform their intended function, such as allow irrigation releases to be made to downstream cropland.

b) The role of on-site personnel

Regular, thorough visual inspection is the primary means of obtaining periodic, site specific information regarding the performance and behavior of a dam under a range of natural and socio-economic impacts. A series of inspection reports can be used to assess changes in the dam's performance and behavior over time. The on-site staff of operation and maintenance personnel represent the first line of defense against adverse dam performance as they have knowledge of the normal behavior of the structure and are often the first to notice changes inthat behavior. It is vital that on-site staff is trained to recognize the signs of adverse dam performance so they are equipped with the knowledge to report changes in behavior to those responsible for taking corrective actions to ensure the safety of the downstream public and foster food crop security. As a result, there is a direct connection between the day-to-day work at the dam and the safety of the Vietnamese public.

1.2 Common Earthfill Dam Features

The typical features of an earthfill dam are shown on Figure 1.

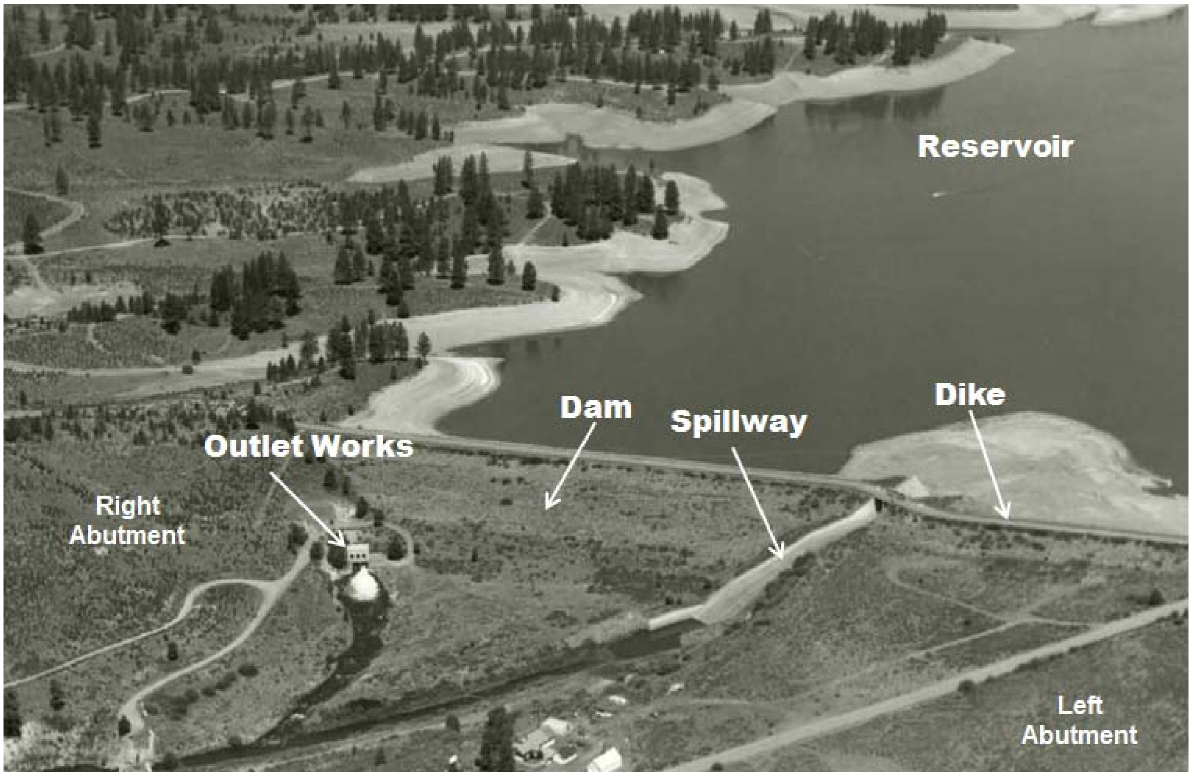

Figure 1: Typical Earthfill Dam Features

The dam and dike embankments are the primary water storage barriers and are normally constructed from on-site soil and rock material to limit construction costs.

The spillway is the primary method to pass inflows out of the reservoir to prevent overtopping failure of the dam and dike embankments which may result in dam break. Depending on each particular case, the spillway can be vertical, horizontal, siphon, tunnel, etc. The spillway can be designed with or without control valve. When having a control valve, the reservoir can store a larger amount of water and the water discharge can be controled more effectively to ensure the safety of primary dam features and downstream area.

The outlet works is the feature used to release reservoir water in a more controlled day-to-day manner to benefitdownstream water users and maintain instream flows for aquatic habitat.

An abutment is that portion of the natural canyon walls that is in contact with the dam embankment. Abutments are described in terms of their location relative to the dam. When standing on top of the dam, looking downstream, the right abutment is located to your right and the left abutment on your left. This standard terminology for right and left is also useful to describe the location of observations made during dam inspections.

1.3 Loading Conditions

Earthfill dams are subject to three broad classes of loading which must be resisted. These loading classes include: static loading; flood loading; and earthquake loading. Static loading involves the normal operation of the reservoir and is related to dam failures due to uncontrolled seepage conditions. Flood loading involves the elevated reservoir water surface caused by a flood and can be related to failures caused by either dam overtopping or uncontrolled seepage conditions through the previously untested upper portions of the earthfill. Earthquake loading involves strong ground shaking that can lead to settlement and overtopping of the embankment or uncontrolled seepage through cracks formed in the earthfill. Earthquakes can also lead to overstressing of other features such as spillway gates that can lead to an uncontrolled release of the reservoir.

II. Prior to the Inspection

2.1. Data Review

When planning for an inspection it is important to review information related to the past performance of the dam. At a minimum, the inspector should review the three prior inspection reports and perhaps discuss the performance of primary dam features with the prior inspectors if the reports are not available. During this review, the inspector should pay careful attention to potential problems and reservoir conditions discussed in the previous reports to assess any changes that have occurred over time. It is often helpful to perform inspections at different times of the year to assess the dam's performance during different reservoir conditions.

2. Necessary Tools and Equipment

A few tools are often helpful to carry when performing an inspection of an earthfill dam. A method of recording observations is necessary and could include a notebook, pencil, and digital camera. The notebook and pencil are used to describe any observation and record its location and size. The camera is helpful to document the inspection observations for record keeping purposes and to aid in communicating information to those not present during the inspection.

A hammer is another important tool to carry during an inspection. The hammer can be used to tap concrete surfaces to aid in listening for deterioration. Good quality concrete will ring when struck with the hammer. If there is a void underlying the concrete or the concrete has become separated from the reinforcing steel the sound when struck will be a much duller tone. Alternatively, for large areas of concrete a heavy chain can be dragged which can produce the same sounds.

A tape measure is also useful for measuring the size and location of the observations made by the inspector. A steel rod may be useful for probing voids, depressions, or other areas. In addition, binoculars can also be useful for looking at the embankment, abutments, or reservoir rim areas from larger distances.

Prior to the inspection it is also wise to perform routine maintenance such as vegetation removal. The removal of excess vegetation will allow the inspector a much better view of the ground conditions at the dam, possibly expose seepage areas, and potential threats or other problems that were not observed previously.

III. Performing the Inspection

Methods for performing an inspection of an earthfill dam vary depending on: the size of the group doing the inspection; specific features at the dam; reservoir conditions; and time of year. Ideally, the dam will be inspected at various times of the year and reservoir conditions to evaluate any changes in its behavior.

However, the procedures for performing these inspections under various conditions are generally similar and include an "all senses approach". This means that the dam inspector should use their sight, hearing, and sense of touch throughout the inspection to evaluate every surface of the facility (e.g., upstream and downstream slopes; crest; downstream toe; groins; spillway; and outlet works). The inspector should sight down linear features,if present, such as parapet walls located on the crest or spillway walls, looking for misalignment that may indicate instability or movement. The inspector should inspect the earthfill slopes by moving up and down the slope to ensure coverage of the entire embankment.If there are a team of inspectors they should spread out to ensure that the entire surface of the dam is inspected.

The inspector should use her/his hearing to listen for flowing water below the surface of upstream riprap, slope protection, areas near the spillway and outlet work or in areas with heavy vegetation. In addition, the inspector can check concrete surfaces by tapping with a hammer or dragging a chain. These and other procedures are discussed herein.

IV. Earthfill Dam Problems

4.1 General

Since the purpose of an examination is to identify signs or phenomenons which can show or lead to existing and potential dam safety problems. The following are discussed:

- The kinds of problems commonly encountered on earthfill dams
- The impact problems have on the safety of a dam
- The actions that should be taken when problems are identified.

Earthfill dams are subject to several different types of problems. These problems include: seepage; cracking; instability; depressions; and maintenance concerns. Maintenance concerns include: inadequate slope protection; surface runoff erosion; inappropriate vegetation; and animal burrows which includes termites and other burrowing insects.

4.2 Seepage

All earthfill dams have water movement through gaps inside the earth material of their embankment and/or foundation materials. The passage of water through the embankment or foundation from the upstream (where has higher water level) to the downstream (where has lower water level) is called seepage.Seepage can lead to the problem of suffosion when embankment or foundation's earth materials are moved by the water flow, or when excessive pressure builds up in the dam or its foundation. Seepage that is not controlled when designed seepage/drainage features incorporated in the dam and foundation are not working properly is often referred to as uncontrolled seepage.

1. Earthfill dam failures caused by uncontrolled seepage is a major cause of earthfill dam failure. Earthfill dam problems associated with seepage can be divided into two categories: dam's slope stability problems and seepage problems.

Seepage causes stability problems when high water pressure and saturation in the embankments and foundations cause the earth materials to lose strength. If uncontrolled seepage emerges on the lower downstream slope, very often the seepage will cause sloughing or even massive landslides.

Seepage can also lead to erosion of the earthfill within the dam called "internal erosion". This concern is especially problematic along conduits through the dam or other penetrating structures such as a spillway training wall or along the contact between the earthfill and foundation.

When uncontrolled seepage exits the ground surface or dam slope in a churning or boiling action due to excessive seepage pressures caused by high hydraulic gradient conditions, it is referred to as a sand boil. Earth material may or may not be exiting with the seepage. Signs that exiting seepage is carrying earth materials are discussed below.

2.Uncontrolled Seepage Appearance

Uncontrolled seepage varies in appearance. Seepage may appear as a wet area or as a flowing "spring." The appearance of, or changes in vegetation are also good indicators of seepage as shown on **Figure 2**. Areas with a lot of water-loving vegetation, such as cattails, reeds, and mosses, should be checked for seepage, as should areas where the normal vegetation appears to be greener or more lush. These patches of lush vegetation are more obvious in arid environments but may also be seen in Viet Nam.

Figure 2: Example of Changing Vegetation Due to Seepage

Viewing the downstream dam face from a distance is sometimes helpful in detecting subtle changes in vegetation. Greener or very lush vegetation below a certain elevation on the downstream face may indicate the intersection of the seepage line through the dam with the slope.

The contacts between the downstream slope and the abutments are especially prone to seepage because compaction is more difficult in these locations than other parts of the fill, and are therefore less watertight. Also, improperly sealed porous abutment rock can introduce abutment seepage into and along the embankment/abutment contact.

Difficulties with compaction also make areas adjacent to conveyance structures like outlet works conduits, spillway conduits, and penstocks more susceptible to uncontrolled seepage problems. Seepage exiting from around or adjacent to conveyance structures is particularly alarming because it may also indicate that there is a crack or opening in the structure that is allowing reservoir water under pressure into the embankment. Rapid internal erosion and an eventual breach of the dam can result.

3.Seepage: Inspection Actions

If uncontrolled seepage is observed, then it should be monitored. To monitor seepage, the following should be recorded: the location(s) of where the seepage is exiting the soil and/or rock; seepage flow rate and clarity; and the level of the reservoir at the time of the observation. In addition, the occurrence of recent precipitation that could account for what appears to be seepage and other weather conditions should be noted. Notes, sketches, and photographs are useful in documenting and evaluating seepage conditions.

The amount of seepage usually correlates with the level of the reservoir. Generally, as the level of the reservoir rises, the seepage flow rate increases. An increase in a seepage flow rate for a given reservoir elevation is cause for concern. In addition, a decrease in seepage flow rate for a given reservoir elevation is also cause for concern as it may indicate that the flow path is changing for some reason.

In some cases, dye can be used to confirm that the reservoir is the source of seepage. A dye test is not a routine procedure. The length of time it takes to conduct a test may vary since the dye may take different amounts of time to penetrate the embankment or foundation. In most cases, records of seepage volumes that correlate with reservoir (dam and water level inside the reservoir) elevations are needed to show that seepage comes from the reservoir.

If sand boils like that shown on **Figure 3** are observed they should be photographed and their location documented. The clarity of the exiting seepage should be noted. If there are any deposition cones around the seepage exit points, this should also be recorded. Flow rates should be measured or estimated along with the corresponding reservoir elevation. However, the seepage flow rates may be difficult to ascertain since sand boils are often under water.

Figure 3: View of a Typical Sand Boil

Sometimes as a temporary measure, a sandbag dikeas shown on **Figure 4** can be placed around a sand boil to increase the depth of water over the boil and thereby decrease the potential for internal erosion along the seepage flow path inside the dam or foundation. Conversely, draining a seepage pond at the toe of a dam may increase the potential for internal erosion along the flow path.

Figure 4: View of a Sandbag Dike Around a Sand Boil and Seepage Flow Measurement

An internal erosion condition does not always appear first as a sand boil. In fact, internal erosion can occur into voids in rock foundations. This type of internal erosion is difficult to detect since nothing is visible until the embankment starts to collapse into the underlying void, or until a vortex appears in the reservoir. A vortex is the rotational movement on the reservoir surface that can appear as water rapidly enters a seepage pathway as shown on **Figure 5**.

Figure 5: View of Typical Vortex or Whirlpool within the Reservoir

Weirs and flumes can be installed to quantitatively monitor seepage exiting from the embankment or foundation. When properly calibrated and kept free of silt and vegetation, weirs and flumes can measure seepage accurately. Weirs that become filled with sediment may indicate that embankment or foundation material is being eroded out of the dam, or simply that sediment from surrounding surface runoff erosion is collecting in the structure.

Many earthfill dams have toe drains that collect and discharge internal embankment and foundation seepage. Before conducting an examination of an embankment dam that has toe drains, the design drawings should be reviewed to determine the location of the toe drains and their outfalls. In addition, previous data on both the reservoir level and flow rate from the drain(s) should be reviewed. Data on drain flow must be looked at in conjunction with reservoir-level data. Knowing how the reservoir level affects the drain flow can help in determining if there is a problem. If flow from a drain is unusual for the given reservoir level, more investigation may be necessary.

During an inspection, the inspector should locate each toe drain outfall and measure the flow. A simple method of measuring the flow from a toe drain outfall is to catch the flow from the pipe in a container of known volume and to time how long it takes to fill the container. The flow rate is usually recorded in liters per minute. Once measured, the inspector can compare the amount of flow measured with the amount of flow anticipated for the current reservoir level based on previous readings.

A drain that has no flow at all could simply mean that there is no seepage in the area of the dam serviced by the drain. However, an absence of flow could also indicate a problem. If a drain has never functioned, it could mean that the drain was designed or installed incorrectly, or that it flowed at one time but has now stopped flowing because it may have become plugged or the seepage path has changed. A plugged drain can be a serious problem because seepage may begin to exist in higher place on the embankment, or may contribute to internal pressure and instability. If possible, blocked drains should be cleaned so that the controlled release of seepage may be restored. Conversely, an increase in drain flow may indicate that the core is becoming less watertight. Recording drain flow rates and reservoir levels over time will help in assessing a dam's seepage conditions.

In addition to measuring the flow rate of seepage, the clarity of any seepage observed should be evaluated. Turbidity means that the water passing through the embankment or foundation is carrying soil with it. Thus, turbidity is cause for concern. Each time seepage is monitored, the clarity should also be visually checked and recorded. In addition, care should be taken when approaching the area of known or suspected seepage to ensure that the inspector does not accidentally cause disturbance to the area and additional turbidity that may not have been present in the seepage.

As mentioned previously, the rate and turbidity of seepage flow should be recorded at each examination. If seepage problems are suspected, then more frequent examinations or further investigation should be considered.

4.3. Cracking

Another potentially serious deficiency is embankment cracking. Cracks may appear in the crest or slopes of the dam. Cracking in an earthfill dam falls into the following three major categories: (i) longitudinal cracking; (ii) transverse cracking; and (iii) desiccation cracking.

1. Longitudinal Cracking and inspection actions

Longitudinal cracking occurs in a direction roughly parallel to the length of the dam as shown on **Figure 6**. It can be an indication of:

- uneven settlement between adjacent embankment zones of differing compressibility;
- excessive settlement and lateral spreading of the embankment; or
- an unstable slope. In this case, the crack may appear arc-shaped.

Figure 6: Example of Longitudinal Cracking

Longitudinal cracks allow water to enter the dam. When water enters the dam the strength of the earthfill material adjacent to the crack may be lowered. The lower strength of the earthfill material can lead to or accelerate a slope stability problem. Longitudinal Cracking: Inspection Actions

If longitudinal cracking is observed the inspector should photograph and record the location, depth, length, width, and offset of each crack observed. Following the initial observation of the crack it and the adjacent embankment should be monitored periodically to evaluate any changes.

2. Transverse Cracking and inspection actions

Transverse cracking appears in a direction roughly perpendicular to the length of the dam as shown on **Figure 7**. If these cracks extend into the core below the reservoir level they are especially dangerous because they could create a path for concentrated seepage through the dam core. Transverse cracks usually appear on the dam crest, near abutments, and in U-shaped or trapezoidal-shaped valleys.

Figure 7: View of Severe Transverse Cracking of an Earthfill Structure

The presence of transverse cracking indicates differential settlement within the embankment or underlying foundation. This type of cracking frequently develops when:

- compressible embankment material overlies steep or irregular rock abutments;
- there are zones of compressible material in the dam foundation.

Transverse cracks may provide a direct path for seepage through the embankment. When the depth of the crack extends below the level of the reservoir, very rapid erosion of the dam may occur, eventually breaching the dam.

Transverse Cracking: Inspection Actions

Similar to longitudinal cracking, if transverse cracking is observed the inspector should photograph and record the location, depth, length, width, and offset of each crack observed. Following the initial observation of the crack it and the adjacent embankment should be monitored periodically to evaluate any changes. Given that these cracks can lead to direct seepage through the earthfill, the cause of these cracks should be determined and the earthfill cracks repaired.

3. Desiccation Cracking and inspection actions

Desiccation cracking is caused by the drying out and shrinking of certain types of soils such as clay. Desiccation cracks usually develop in a random, honeycomb pattern as shown on **Figure 8**. Typically, desiccation cracking occurs in the crest and the downstream slope.

Figure 8: View of Typical Desiccation Cracking (also note the animal burrow at arrow)

Usually, desiccation cracking is not harmful unless it becomes severe. The major threat of severe desiccation cracking is that this type of cracking can contribute to the formation of gullies. Surface runoff erosion concentrating in the desiccation cracks or gullies can result in eventual damage to the dam.

Also, heavy rains can fill up these cracks and cause portions of the embankment to become unstable and to slip along crack surfaces where the water has lowered the strength of the earthfill material. Deep cracks that extend through the core conceivably can cause a breach of the dam when the reservoir rises and the soil adjacent to the cracks does not swell rapidly enough upon wetting to reseal the area.

Desiccation Cracking: Inspection Actions

If desiccation cracking is observed, the inspector should probe the more severe cracks to determine their depth, especially if they are oriented in an upstream/downstream direction. In addition, the inspector should photograph and record the location, length, width, depth and orientation of any severe cracks observed and compare these measurements with past measurements to determine if the condition is worsening.

If the depth of the cracking extends below the reservoir level or potential reservoir level, appropriate remedial measures should be recommended.

4.4 Instability

Instability of an embankment can be very serious. Embankment instability is referred to variously as slides, displacements, slumps, slips, and sloughs. An example of a slide feature is shown on **Figure 9**.

Figure 9: View of a Typical Slide Feature Indicating Instability of the Slope

Slides can be grouped into two major categories: shallow slides; and deep-seated slides

1. Shallow Slides and inspection actions:

Shallow Slides can occur on the Upstream Slope or Downstream Slope

Shallow slides in the upstream slope are often the result of an overly steep slope aggravated by a rapid lowering of the reservoir. Shallow slides in the upstream slope pose no immediate threat to the integrity of the dam. However, shallow slides may lead to:

- obstruction of water distribution structure inlets;
- larger, deep-seated slides.

2. Shallow Slides: Downstream Slope

Shallow slides in the downstream slope also indicate an overly steep slope. In addition, these slides may also indicate a loss of strength in the embankment material. A loss of strength in the embankment material can be the result of saturation of the slope from either seepage or surface runoff. Additional loads from structures can aggravate the condition.

Shallow Slides: Inspection Actions

If shallow slides are observed, an inspector should: (i) photograph and record the location of the slide; (ii) measure and record the extent and displacement of the slide; (iii) look for any surrounding cracks, especially uphill from the slide; (iv) check for seepage near the slide; and (v) monitor the area to determine if the condition is becoming worse.

3. Deep-Seated Slides and inspection actions

Deep-seated slides are serious threats to the safety of the dam. Deep-seated slides are characterized by:

- well-defined scarping (a scarp is a steep back slope of the slide);
- toe bulge (a toe bulge is produced by the rotational or horizontal movement of embankment material); and
- arc-shaped cracks (arc-shaped cracks in the slope are indications that a slide is beginning. This type of crack may develop into a large scarp in the slope at the top of the slide as it begins to move downward).

Deep-Seated Slides: Inspection Actions

A deep-seated slide in either the upstream or downstream slope may be an indication of serious structural problems. In most instances, deep-seated slides will require the lowering or draining of the reservoir to prevent the possible breaching of the dam.

If a slide is suspected, the inspector should: closely inspect the area for cracking or scarps which indicate that a slide is the cause; recommend an investigation to determine the magnitude and cause, if a deep-seated slide is considered probable; recommend possible lowering and restricting the reservoir if the ability to make reservoir releases is threatened by continued movement of the slide.

4.5 Depressions

1. Overview

Depressions are low spots in embankment surfaces and may be localized or widespread as shown on **Figure 10**.

Figure 10: View of Depressions on the Dam Crest

Depressions may be caused by:

- Settlement in the embankment or foundation. Such settlement may result in a loss of freeboard and represent a potential for overtopping of the dam during large floods;
- Wave action erosion against the upstream slope that removes embankment material or bedding from beneath riprap may form a depression as the riprap settles into the vacated space;
- Livestock activity and vehicle traffic can also cause depressions;
- Internal erosion or piping and subsequent collapse of overlying material.

Some areas of the embankment surface that look like depressions may be the result of improper final grading during construction or where trees have been removed but the void occupied by the roots left un-backfilled, but the cause of depressions should be determined. In addition, in some cases, settlement of backfill may also leave a depression. Depressions can be minor or they can be very serious. Sinkholes are a serious type of depression.

A good way of distinguishing between localized settlement and sinkholes is to look at their profiles. Localized settlement usually has gently sloping, bowl-like sides and is normally larger in area. Sinkholes usually have steep sides from the soil shearing as it collapses into an underlying void (**Figure 11**) and are often smaller is surface area. If a sinkhole is located within the reservoir, the inspector may observe a whirlpool at the reservoir water surface as shown on **Figure 5**. This situation should be considered extremely serious as the internal erosion of the embankment has progressed all the way through the earthfill.

Figure 11: View of a Sinkhole on the Dam Crest (not the near vertical sides)

Depressions as well as other misalignment in the crest and embankment slopes often can be detected by sighting along linear features such as guardrails, parapet walls, or pavement striping. Some apparent misalignment may be due to irregular placement of those features. For this reason, irregularities should be monitored and evaluated over time to verify any changes in suspected movement.

Monitoring of irregularities is facilitated by surveying permanent monuments across the crest to determine the exact location and the extent of misalignment. A record of survey measurements also can establish the rate at which movement is occurring and aid in decision making.

2. Settlement: Inspection Actions

Although settlement, in most cases, does not represent an immediate danger to the dam, it may be early indicators of more serious problems. Therefore, an inspector should: photograph and record the location, size or extent, and depth of any settlement (a survey of the crest can be performed if there is a concern about loss of freeboard); probe the bottom of localized depressions to evaluate whether or not there is an underlying void or flowing water that would indicate that a sinkhole exists that is caused by the removal of subsurface material by internal erosion or piping; and inspect the depression frequently to ensure it is not continuing to settle or enlarge.

3.Sinkholes: Inspection Actions

If a sinkhole is encountered this should be considered a very serious concern. An inspector should:
(i) probe the bottom of the sinkhole to determine if a larger void exists or a large void may be visible from the ground surface in some cases; photograph and record the location, size, and depth of the sinkhole; and recommend that the cause of the sinkhole be investigated immediately and that the threat to the dam be

4.6 Maintenance Concerns

Maintenance includes the measures taken to protect and maintain a dam’s structure quality in a serviceable condition. While poor maintenance may not immediately threaten the safety of a dam, if maintenance is neglected, deficiencies may worsen and become dam safety issues. Deficiencies associated with inadequate maintenance include:

- inappropriate vegetation;

- inadequate slope protection;
- surface runoff erosion; and
- animal/termite burrows.

1. Inappropriate Vegetation

Inappropriate vegetation is another common maintenance problem. Inappropriate vegetation growth generally falls into two categories: excessive vegetation or deep-rooted vegetation. In general, inappropriate vegetation should be cleared from the dam and abutments within approximately 10 meters of the earthfill embankment.

a. Excessive Vegetation

Excessive vegetation is a problem wherever it occurs on an earthfill dam. Excessive vegetation can:

- obscure large portions of the dam, preventing thorough visual inspection. Problems that threaten the integrity of the dam can develop and remain undetected if they are obscured by vegetation;
- prevent access to the dam and surrounding areas. Limited access is an obvious problem both for inspection and maintenance, and especially during emergency situations, when access is crucial;
- provide a habitat for burrowing animals. Burrowing animals can pose a threat to embankment dams by causing piping.

Also, there should be no vegetation in the riprap on the upstream slope. Vegetation in the riprap promotes displacement and degradation of the slope protection and can present a tripping hazard to the inspector. Vegetation should be controlled by periodic mowing or other means. To ensure that the greatest visibility of the slopes and crest, examinations should be scheduled shortly after mowing has been completed.

b. Deep-Rooted Vegetation

Although a healthy cover of grass is desirable as slope protection, the growth of deep-rooted vegetation, such as large shrubs and trees, is undesirable. Treescan be blown over and uprooted during a storm. The resulting hole left by the root system could breach the dam or shorten a seepage path and initiate internal erosion.

Root systems associated with deep-rooted vegetation develop and penetrate into the dam’s cross section. When the vegetation dies, the decaying root system can provide paths for seepage and cause internal erosion to occur. Even healthy root systems of large vegetation can pose a threat by providing seepage paths. These seepage paths eventually can lead to internal erosion and threaten the integrity of the earthfill dam.

It is generally agreed that trees and shrubs more than 0.6 meters high are undesirable growing on or adjacent to embankment dams. However, there is some debate in the engineering community over when and how to remove well-developed trees and root systems that are already in place in the dam. The location, size, type of tree, and prevailing MARD policy will determine the course of action at a given dam.

The best approach to trees on the crest, slopes, and adjacent to the dam is to cut them down before they reach significant size. If large trees have been cut down, the root system should be removed (and earthfill repaired) when the reservoir is low to ensure a safe condition during this activity.

c. Inappropriate Vegetation: Inspection Actions

An inspector should: (i) look for excessive and deep-rooted vegetation on all areas of the dam; (ii) make sure that there is no vegetation growing in the riprap on the upstream slope; and (iii) check for signs of seepage around any remaining stumps or decaying root systems on the downstream slope, groin, or toe areas.

If inappropriate vegetation is observed, the size and extent of the vegetation should be recorded and photographed and actions taken to eliminate the vegetation including prevention of future growth.

2. Inadequate Slope Protection

Slope protection is designed to prevent erosion of the embankment slopes. There are two primary types of slope protection used on embankment dams: riprap and vegetative cover (grasses).

Gravel, soil-cement mixtures, concrete, asphalt, and other types of slope protection are also used. The type of slope protection selected depends upon economics, and rainfall conditions, and the size of the reservoir and wind conditions found at the site.

a. Riprap

Riprap is rock, usually broken or angular, placed on the upstream and/or downstream slopes of embankment dams to provide protection from erosion caused by wave action, surface runoff erosion, and wind scour. Properly designed upstream riprap slope protection is made up of at least two layers of material:

- The inner layer(s), called the filter layer or bedding, is sand and gravel-size rock properly sized and graded to prevent the underlying embankment from being washed out through the voids in the larger rocks found in the outer layer;

- The outer layer is cobble-size and boulder-size rock that is large enough not to be displaced by wave action. These larger rocks prevent wave erosion.

b. Vegetative Cover

The outer soil portions of the earthfill dam must be protected from wind and rainfall runoff erosion as well as wave erosion. Failure to protect the slope could result in the formation of beaching or significant erosion rills or gullies that will eventually have to be repaired. In most geographic areas, a properly cultivated cover of grass provides satisfactory crest and downstream slope protection. The root system of the vegetative cover holds the surface soil in place and protects the slopes from wind and surface runoff erosion. In some areas, gutters to convey runoff safely off of the dam are used to limit the potential for serious erosion.

Using a grass cover to protect the upstream slope may also be effective for small reservoirs and dams that have insignificant wave action. However, it may be necessary to use other types of slope protection:

- where riprap is unavailable or too costly to obtain and place;

- in areas of the dam where surface runoff is excessive or concentrated; and

- where conditions combine to create severe wave action.

The constant action of waves on the upstream slope may result in beaching and degradation of the slope protection. Unless measures are taken to maintain adequate slope protection, wave action will begin to erode the underlying earthfill material. The effects of severe wave action on the upstream slope can include:

- Beaching. Beaching is the displacement by wave action of a portion of the upstream slope of the embankment. When beaching occurs, earthfill material is deposited farther down the slope. In this form of erosion, the slope protection (i.e., riprap or vegetative cover) and underlying material can be removed. A relatively flat area, or beach, with a steep back slope or scarp is formed. The continuance of this process can lessen the width and possibly height of the embankment, and could lead to increased seepage, instability, or overtopping of the dam;

- Degradation of the slope protection. Degradation may occur when the protective material cracks and breaks down due to weathering and wave action. Even the best designed slope protection will experience some degradation over time. Degraded riprap, soil-cement mixtures, or other slope protection should be monitored and inspected. If evidence shows that damage to the earthfill is occurring, degraded slope protection must be repaired or replaced.

c. Inspection Actions for Inadequate Slope Protection:

It is important to check that the riprap is large enough and sufficiently angular and durable such that it is not displaced by wave action and that it is not breaking down into smaller fragments. Irregular sized and shaped rocks create an interlocking mass that prevents waves from passing between the larger rocks of the outer layer and removing the underlying bedding material.

The slope upon which the riprap is placed must be flat enough to prevent riprap from dislodging and moving down the slope. Hand-placed riprap, while usually providing good protection, is typically a relatively thin blanket of protection. Hand-placed riprap is susceptible to failure because the dislodging of one large rock may cause displacement of the surrounding rock due to a lack of adequate support. However, most modern riprap is dumped in place, resulting in a much thicker-layered blanket of protection.

An inspector should:

- ensure that the slope protection is adequate to prevent erosion;

- look for beaching, displacement, and degradation of the slope protection.

If inadequate slope protection is observed: the findings should be recorded and the area photographed; the extent of embankment damage (i.e., earthfill material removed) should be determined; and corrective action should be recommended to repair or to replace the inadequate slope protection.

3. Surface Runoff Erosion

Surface runoff erosion is one of the most common maintenance problems of embankment structures. If not corrected, surface runoff erosion can become a more serious problem. The worst damage from surface runoff is manifested by the development of deep erosion gullies on the slopes, both at the groins and in the central portion of the dam.

Gullies can cause breaching of the crest and can shorten the seepage path through the dam or abutments, possibly leading to internal erosion. Gullies can develop from poor grading or sloping of the crest that leads to improper drainage, causing surface water to collect and to run off at the low points along the upstream and downstream crest edge. Gullies caused by this type of runoff eventually can reduce the cross-sectional area of the dam and lower the crest elevation if not addressed in a timely way.

Bald areas or areas where the protective cover is sparse are more susceptible to surface runoff erosion problems. On the upstream slope, erosion may undermine the riprap and cause it to settle. Settlement of the riprap may lead to the eventual degradation of the slope itself.

The crest also can experience weathering and erosion if it is not adequately protected. Crest erosion protection may consist of a road surfacing such as gravel, asphalt, or concrete pavement. The type of crest protection used depends on the amount of traffic anticipated. If little or no traffic is expected on the crest, a grass cover may be adequate. Too much traffic on gravel- or grass-covered crests, especially during rainy periods, can lead to ruts in the crest surface. Ruts are undesirable because they will pond water, potentially causing stability problems.

There are a number of special circumstances that can contribute to or initiate surface erosion of the crest, upstream and downstream slopes. In some areas, livestock may establish trails on the embankment. Livestock traffic can damage the slope's vegetative cover.

During Inspection Actions for Surface Runoff Erosion, An inspector should:

- make sure that the slope and crest protection is adequate to prevent erosion and covers the entire area;
- look for gullies, ruts, or other signs of surface runoff erosion. Make sure that the upstream and downstream shoulders of the crest are checked for low spots since surface runoff can concentrate in these areas;
- check for any unique problems, such as livestock or fishermen, which may be contributing to erosion.

If surface runoff erosion is observed: the findings should be recorded and area photographed; the extent or severity of the damage determined; and corrective action should be taken to repair the areas damaged by surface runoff and measures taken to prevent more serious problems.

4. Animal Burrows

In some instances, animal burrows can damage the structural integrity of a dam, since they weaken the embankment and can create pathways for seepage.

Some the animals that can cause problems on embankment dams are:

- rodents;
- snakes; and
- insects.

Burrowing animals can damage the earthfill in their search for food and by making nests and passageways in the embankment. These passageways may cause internal erosion failures when they extend to r to the upstream slope, shorten seepage pathways, or penetrate the core of the dam.

The location and depth of burrows and the cross-sectional width of the embankment determine the seriousness of the problem. Shallow burrows or burrows that are confined to one side of the embankment, or burrows that are lower on a slope with a broad cross-section may be less dangerous than deep passageways on a narrow cross-section. Inspection Actions for Burrowing Animals:

If burrowing animals or their disturbance are evident:

- look for any evidence of seepage coming from any of the burrows on the downstream slope or foundation; and

- estimate the location and depth of the disturbance and document areas with photographs for comparison during future inspections to determine if the problem is getting worse.

In addition, if the disturbance appears to present a threat to the dam, it should be recommended that the burrowing animals be removed or eradicated (although removal of burrowing animals is always beneficial, whether or not they pose an immediate threat to the integrity of the dam).

V. Spillway and Stilling Basin Problems

5.1 General

Similar to earthfill dams, inspection of the spillway and stilling basin is intended to identify conditions that are either immediate dam safety concerns or could lead to a dam safety concern in the future if not addressed in a timely way. Spillway and/or stilling basin problems could lead to reduced release capability or perhaps failure of the structure and could contribute to a breach of the dam and dam safety itself.

Spillway and stilling basin inspections should be performed as a portion of the routine overall inspection of the facility. In addition, the spillway and stilling basin should be inspected periodically during and after their operation to verify adequate performance in service.

There are many different types of spillway and stilling basin which have specific advantages and shortcomings in their design. However there are common problems associated with most spillway and stilling basin designs including: debris plugging; erosion; inappropriate vegetation; spillway wall or crest structure instability; and general deterioration of other dam structures. In addition, stilling basins can suffer from a loss of their ability to adequately dissipate the energy of the spillway discharge.

5.2 Debris Plugging

Debris plugging, as the name suggests, involves debris from the reservoir accumulating in the spillway inlet, crest structure, gates (if present), or spillway channel that reduces the ability of the feature to discharge flows at its full capacity. An example of a major debris plugging problem is shown on **Figure 12**. Conditions that contribute to debris plugging problems way not be within the control of the dam operations personnel such as development or wildfires upstream of the reservoir which can contribute to debris loading during flood events.

Figure 12: Example of Major Debris Plugging of Spillway

The inspector should periodically scan the reservoir and its shoreline visually to detect the presence of large debris that could be moved during a flood and carried towards the spillway. Such debris should be periodically removed from the reservoir and disposed of. In addition, all features of the spillway itself should be kept clear of any obstructions that could contribute to debris plugging problems. During spillway discharges on-site personnel should periodically monitor for debris plugging problems. If debris begins to become a concern, sometimes it can be dislodged and guided downstream by the flow before significant buildup and plugging has occurred.5.3 Spillway Erosion and Cavitation

Spillways walls and channels can be composed of a variety of materials including: concrete; rock or masonry; or perhaps soil. Each of these materials has different resistance to erosion by spillway flows. Spillway erosion can lead to failure of the spillway and eventually to breach of the dam in some cases. An example of spillway erosion is shown on **Figure 13**.

Figure 13: Example of Significant Spillway Erosion (at arrow)

A special kind of spillway erosion is called cavitation. During certain conditions that include high velocity flow, if the water changes direction rapidly very high negative pressures are created which tend to initiate erosion of materials even considered to be very resistant (such as concrete and steel). Conditions that can lead to the change in flow direction necessary to initiate cavitation can include irregularities in the spillway channel like concrete spalling or cracking, irregular rock or soil surfaces, or simply improper design and construction. Once cavitation initiates, it can be expected to continue and get worse throughout the flood event as the defect causing initiation continues to grow.

During routine inspections (and following significant spillway discharges) the inspector should look for signs of erosion or other deterioration of the spillway channel and walls that could lead to cavitation problems. For concrete spillway channels, large spalls or cracking and/or joint offsets that extend into areas of high velocity flow should be carefully noted. For soil lined channels, obvious erosion, uneven surfaces or protruding rocks subjected to high velocity flows should also be noted. Such areas should be repaired prior to the next spillway discharge.

5.4 Inappropriate Vegetation

As discussed previously, things that will reduce the ability of the spillway to pass flow should be removed from the spillway inlet, crest structure, stilling basin and channel. For concrete lines spillways, all vegetation should be removed to prevent damage to the structure. For soil lined spillways only grasses should be allowed to grow and prevent erosion. The grasses should be cut periodically to limit their height and ability to reduce outflows.

In addition, areas where grassy vegetation is lacking within a soil lined spillway should be noted. Revegetation of these areas should be performed to ensure they do not contribute to erosion of the spillway flow surfaces.

5.5 Instability

Instability as it relates to the spillway includes three primary features: the crest structure, spillway walls, and stilling basin walls. Instability of the spillway and stilling basin walls are described together.

1. Instability of the Spillway

Instability of the spillway involves sliding or overturning of the water control portion of the spillway due to water and perhaps earthquake loading. The inspector should look for misaligned or offset portions of the spillway or cracking perpendicular to the axis of the structure or along concrete placement lift lines. Water leakage through horizontal concrete placement lift lines during normal conditions may also indicate that the portion of the structure may be unstable. Instability problems would most likely be observed following an unusual loading condition such as an earthquake or large flood which loads the structure to a level higher than has been observed previously.

If signs of movement of the structure are observed this should be considered extremely serious as the ability of the structure to resist future flood and earthquake loading has been compromised. The inspector should note the location and size of any offset crack or concrete joint observed. Begin periodic monitoring to assess any change in the condition over time until corrective actions can be taken.

2. Instability of the Spillway or Stilling Basin Walls

Instability of the spillway or stilling basin walls involves sliding or overturning of the walls along the sides of the structure as shown on **Figure 14**. The inspector should look for cracking, tilting of the walls, or offset joints or cracks along the wall alignment. In addition, the inspector should look for signs misalignment along the length of the walls.

Figure 14: Overturning Instability of the Spillway Wall

In some cases, there may be holes in the spillway walls along its base, called weep holes, to allow the backfill soil to drain. Water emerging from these weep holes should be noted for quantity and observed for signs of soil movement.

Things that can contribute to instability of the walls include: (i) lack of drainage through the weep holes; (ii) tree or other vegetation growth adjacent to the walls; (iii) earthquake loading; and (iv) equipment, vehicle, or other surcharge loads that were not designed for.

If signs of movement are noted the inspector should estimate and record the amount of movement or tilting of the wall. Normally this estimate is made relative to a portion of the wall that does not appear to be moving. These measurements can be compared over time to evaluate if the wall continues to move or has stabilized.

5.6 General Deterioration

General deterioration of the spillway and stilling basin involves, as the name suggests, normal deterioration that occurs as a result of passing flow through the structures. The inspector should look for signs of erosion of concrete or soil surfaces, loss of support for spillway walls or floor slabs, spalling of concrete, or other unusual conditions.

5.7 Inability of Stilling Basin to Dissipate Energy

Located at the downstream end of the spillway, the purpose of the stilling basin is to dissipate the energy of the flowing water before it is returned to the stream channel preventing excessive erosion. This energy dissipation is normally accomplished using either or a combination of a deep pool, called a plunge pool, or using concrete devices called dentates. The inspector should look for signs of erosion or missing dentates.

In addition, sediment or debris buildup within the stilling basin can reduce its ability to dissipate the energy and can lead to erosion of the stilling basin during operation through a process called ball milling. As a result, the inspector should also look for and estimate the amount of sediment or debris in the stilling basin. This sediment and debris should be periodically removed to extend the service life of the stilling basin.

VI. Outlet and Intake Works

The outlet works includes water release facilities that are used primarily to make operational deliveries to downstream water users or perhaps fish and wildlife releases. The outlet works might also be used to draw down the reservoir in advance of an expected flood event or in the unlikely event that a serious dam safety deficiency is found at the facility. In general, conduits through earthfill dams are responsible for a large percentage of earthfill dam failures due to the difficulty in achieving adequate compaction around the conduit during construction. As a result, inspection of penetrating conduits and the surrounding area is quite important.

Often the interior of the outlet works conduit is not accessible for a visual inspection. In such cases, performing periodic video inspections of the conduit to assess its condition is advisable. However, in some cases the conduit may be large enough to accommodate a visual inspection. Whether the interior of the conduit is inspected using a camera or visually, the inspector should look for issues such as: signs of structural damage (e.g., crushed or deformed conduit sections); offset conduit joints; conduit cracking; conduit deterioration or corrosion; seepage into or out of the conduit; and debris or vegetation buildup at the intake, within the conduit, or at the outfall location. Debris and vegetation can sometimes be removed by a water discharge.

As mentioned previously, penetrating conduits are related to a large percentage of earthfill dam failures. The poorly compacted backfill surrounding the conduit often allows for more significant seepage quantities and velocities that can contribute to internal erosion inside the earthfill structure. Holes or offset conduit joints can allow embankment soil to be eroded into the conduit or can allow pressurized water from the conduit to penetrate the surrounding earthfill contributing to internal erosion. Failure of an earthfill dam due to seepage adjacent to the outlet works conduit is shown on **Figure 15**.

Figure 15: Internal Erosion Failure Due to Seepage Along the Outlet Conduit

As a result, the earthfill in the vicinity of the outlet works (or any penetrating conduit) should be inspected thoroughly. Depressions or sinkholes visible at the ground surface along the conduit alignment should be considered a very serious condition which may indicate that internal erosion has initiated and progressed to an alarming state. The ground surface near the conduit outlet should also be visually checked for seepage and any soil being transported by the flow.

The function of the outlet works gate should also be inspected and tested routinely. The outlet gate(s) should be fully opened and closed to ensure the gate leaf (i.e., the part of the gate which regulates the flow) travels freely. The inspector should note any binding or uneven gate movement. The gate stem (i.e., the portion of the gate that moves the leaf) should be checked to ensure it is straight and that any stem supports are solidly attached. The lubrication of the gate stem should also be checked. Corrosion of the gate components should be noted.

Also, if there are components of the outlet conduit that become exposed during periods of low reservoir storage, these should be inspected.

VII. Record Keeping

Detecting changes in the behavior of the dam over time is one of the key outcomes from a series of dam inspections. As a result, record keeping is important to allow any changes to be assessed. If a change in behavior is noted between two inspections under similar loading conditions, this could indicate a serious condition that should be discussed with leadership.

VIII. Visual Inspection Procedure

8.1. Definition

Visual inspection is aimed at indentifying safety condition of the structure. The visual inspection procedure which includes inspection of earthfill dam and outlet worksthrough survey, investigation, visual inspection, photographs and observation of then refer to other available design porfolio and improvement reports of the reservoirs to give a safety score for each item, component and safety related factors .

Figure 16. General view of Trang Vinh dam, Quang Ninh province

8.2. Content

Visual inspection is done through survey, site investigation, and scoring.

Table 1 shows criteria for assessing safety condition of a construction. Table

Table 1. Criteria for assessing safety condition of a construction

Levels of safety	*Working condition of dam's components and reservoir's key work items (crest, spillway, upstream and and downstream face, foundation, abutment, canall, etc)*	*Score (rank of 100)*	*Conclusion*
I	Ideal condition, no unusual sign	0-40	Safety
II	Needs partial repair to reduce damage, or; Needs tiny improvement of any secondary component; and Other compoments remain safe for operation.	41-70	Rather safety
III	Needs any urgent action as below due to huge break of main	71-100	

	component - Repair - Improvement - Reconstruction, - Stop operating damage		Safety risk

a) Safety of the each work contributes to the safety of the whole system. .

Type I: A dam is safe and operated according to initial design;

Type II: A dam is rather safe, can be operated but needs strict supervision;

Type III: A dam is at risk of unsafety, not allowed to reserve water or to contro; water level, needs strict supervision, inspection, repair and improvement.

The followings are examination items.

1. For the earthfill dam

- Crest: Table 2;
- Upstream face: Table 3;
- Downstream face: Table 4;
- Foundation and two abutments: Table 5.

2. For spillway

- Inlet canal and overflow weir: Table 6
- Outlet canal : Table 7;
- Stilling basin equipment: Table 8.

3. For intake projects and other concrete projects in general

- Intake project: Table 9;
- Other concrete projects: Table 10.

Table 2. Criteria and scoring of safety related factors to dam crest

Factor	***Levels of safety***	***Score***	***Description of safety related factors to dam crest***
Vertical and horizontal crack	I	0-40	Ideal safety condition, no vertical and horizontal crack
	II	41-70	Length of vertical and horizontal crack is from 0 to to5m, equal or smaller than 10to50% of dam crest.
	III	71-100	Length of vertical/ horizontal crack ≥ 5m, ≥ 50% of dam crest, horizontal crack comes deeply under the water level of reservoir and barrier wall is inclined.
Settlement	I	0-40	Ideal safety condition, no damage .

Factor	Levels of safety	Score	Description of safety related factors to dam crest
	II	41-70	Whole settlement or partly settlement of each component with non-dangerous status, < 50cm. The safety is still ensured.
	III	71-100	Safety condition is at risk because the settlement is over allowed limit or partialresettlement ≥ 50cm, slope of pavement on the dam crest and slope of dam are lowered and trend to increase to concrete dam foundation within 0.6m.
Horizontal displacement	I	0-40	“Ideal” safety condition, no defect
	II	41-70	Normal safety condition: with sign of horizontal displacement (vertical displacement 0 - 50cm and horizontal displacement 0 - 30cm).
	III	71-100	Safety condition is at risk: deformation on dam crest by over horizontal displacement (vertical displacement ≥ 50cm, vertical displacement ≥ 30cm).
Damage on wave barrier wall	I	0-40	Ideal safety condition, no defect
	II	41-70	Damaged area of barrier wall on dam crest ≤ 15m^2.
	III	71-100	Safety condition is at risk: if any of damage on barrier wall of the dam crest ≥ 15m^2 (slight increase of these signsleakage and settlement, deep collapse, color change of leaking flow, etc).
Slope of dam crest	I	0-40	Relative ideal safety condition
	II	41-70	Damaged condition with the case that length slipes deeply into dam body ≤ 2m.
	III	71-100	Safety condition is at risk if length of deep slipes deeply into dam body ≥ 2m.

Table 3. Criteria and score of safety related factors to safety of upstream face

Factor	Levels of safety	Score	Description of safety related factors to upstream face
Penetration from dam body	I	0-40	The best safety condition. No leakage over allowed limit from dam body.
	II	41-70	Normal safety condition because of light increase in leakage from dam body
	III	71-100	Safety condition is at risk because ofbubble or eddy on the reservoir face by over leakage from dam body, the water level in reservoir is lowered and the upstream face is settled.
Settlement and	I	0-40	The best safety condition, no damagedamage
	II	41-70	Settlement is 0 - 50cm or deformation is 0 - 50% of upstream

deformation			dam face.
	III	71-100	Safety condition is at risk: due to more damage than above cases (settlement ≥ 50cm or deformation ≥ 50%).
Damage of anti-leakage equipments	I	0-40	The best safety condition, no damagedamage of anti-leakage equipments
	II	41-70	Condition have light damage (crack on upstream dam face < 0.1mm, connection section is opening < 2mm, probability is 50% of altered concrete)
	III	71-100	Condition have light damage (crack on upstream dam face < 0.1mm, connection section is opening > 2mm, probability is 100% of altered concrete)
Stability of slope and slope protection layer	I	0-40	The best safety condition, no damage,
	II	41-70	Condition with 0 - 50% of upstream face's damage
	III	71-100	Safety condition is at risk with ≥ 50% of upstream face
Scour at upstream dam face	I	0-40	The best safety condition, no damage at upstream face
	II	41-70	Condition with the scour phenomenon at the depth of 0 - 2m on upstream face and damage at some positions of concrete or face protection rock.
	III	71-100	Condition with scour phenomenon at the depth > 2m of upstream face and creating small gutters.

Table 4. Criteria and score of safety related factors to safety of downstream face

Factor	***Levels of safety***	***Score***	***Description of related factor to safety of downstream face***
Leakage from dam body and status of water drainage equipment	A	0-40	The best safety condition and there is no leakage from dam body or there is leakage but water is clear, water drainage equipments operate well
	II	41-70	Normal working condition only begin leaking from dam body (< 1,0 *l*/s), leaking water is clear, water drainage equipments operate well
	III	71-100	Big leakage creates turbid water flow, unusual change in leakage and leakage volume increases double than normal level under the condition that there is not rain (≥ 1,0 *l*/s). Water drainage equipment is damaged.
Face stability	I	0-40	The best safety condition, no damagephenomenon of instability at downstream face.

Factor	*Levels of safety*	*Score*	*Description of related factor to safety of downstream face*
	II	41-70	Small instability due to shallow and small cracks, sliding and settlement and partly moist.
	III	71-100	Small instability due to deep cracks, sliding and settlement and partly moist (water leakage) at downstream area.
Downstream face protection equipment	I	0-40	The best safety condition and there is not sign of damage at downstream face protection equipments.
	II	41-70	Condition with damaged signs at 0 – 50% of downstream face
	III	71-100	Dangerous condition with damaged signs > 50% of downstream face
Scour at downstream face	I	0-40	The best condition, no.
	II	41-70	Medium condition with scour phenomenon at partly downstream face
	III	71-100	Safety condition is at risk with the phenomenon of beginging to form gutters by scour at face.
Plant carpet	I	0-40	The best safety condition and there is tree, grass carpet covering the downstream (besides to downstream face).
	II	41-70	There are short term trees (in the year) arising on downstream face.
	III	71-100	There are long term trees (many years) and bush rising on downstream face
Cave and animal nests	I	0-40	The best safety condition, animal-free
	II	41-70	There are 0 - 4 caves or nests of animals, diameter is 0 - 5cm.
	III	71-100	There are many caves or nests of animals, or caves having diameters ≥ 5cm.

Table 5. Criteria and scoringscoring of safety related factors to safety of foundation and two abutments

Factor	*Levels of safety*	*Score*	*Description of safety related factors to safety of foundation and two abutments*
Settlement and collapse at partly of the foundation and abutment	I	0-40	The best safetycondition, no over settlement and collapse, no partial settlement and collapse, foundation and abutment are stable.
	II	41-70	Normal condition , no over settlement and collapse, partial settlement and collapse, foundation and abutment are sTable
	III	71-100	Safety condition is at risk and instability at foundation and abutment and continue over settlement and partial settlement and collapse to the scope about 0.6m far from concrete dam

			foundation.
Scour and penetration	I	0-40	The best safety condition , because of no acour and over penetration at dam foundation and two abutments. Penetrated water is very clear.
	II	41-70	Small affected condition because of scour and over penetration at partly of dam foundation and two abutments. Water is clear.
	III	71-100	Safety condition is at risk: because gutters are formed, unusual temperature changes of leaking water flow, increasing leaked water volume about double than normal status because ofrain by scour at dam foundation and two abutments, over penetration. Water is turbid.

Figure 17. *Starting area of Go Mieu lake – Thai Nguyen*

Table 6. Criteria and scoringscoring of safety related factors to safety of intake canal and overflow weir of flood drainage

Factor	*Levels of safety*	*Score*	*Description of safety related factors to safety of intake canal and overflow weir of flood drainage*
Damage on the face of concrete and steel structure	I	0-40	The best safety condition , no damage on concrete surface and steel structure.
	II	41-70	There is damage on the face of concrete and steel structure but not dangerous.
	III	71-100	Safety condition is at risk. There is crack on reinforced concrete of steel structure or deformation of concrete panel, foundation rock and steel structure.
Stability of side wall	I	0-40	The best safety condition , no damage on side wall and reinforce layer (outside area).

	II	41-70	Condition are affected little due to that there is damage on crack, leakage at the side wall or reinforced concrete (outermost).
	III	71-100	Safety condition is at risk with damage such as weak water drainage of side wall, crack by soil pressure reinforce at wall side, crack on the face of reinforced concrete (outermost), throbbing phenomenon, etc
Stability of canal banks' slope	I	0-40	The best safety condition and there is instability at natural slope at the upper side on intake canal.
	II	41-70	Condition affected by some rocks falling down slope side, canal of intake canal.
	III	71-100	Safety condition is at risk by internal collapse of natural slope and crack on natural slope at the side of intake canal.
Plant carpet and barrier at intake canal and overflow weir	I	0-40	The best safety condition, no plant covering and because of blocking the intake canal.
	II	41-70	Condition are affected little by plant carpet and barriers in the intake canal.
	III	71-100	Safety condition is at risk because the capacity of dam drainage is controlled due to earth collapse or plant carpet as well as other barriers in the intacke canal.

Table 7. Criteria and scoringscoring of safety related factors to safety of drainage canal after overflow weir

Factor	*Levels of safety*	*Score*	*Description of safety related factors to safety of drainage canal after overflow weir*
Settlement and collapse, displacement and stability of drainage canal protection equipment	I	0-40	The best safety condition, no damageinternal settlement and collapse, displacement or separation of floor tiling panels, breakage of floor panels or peeling off rock at intake canal protection rock.
	II	41-70	Medium condition because of internal settlement and collapse, displacement or separation of floor tiling panels, breakage of floor panels < 2mm, there is signs of peeling off rock at intake canal protection rock.
	III	71-100	Safety condition is at risk due to big big internal settlement and collapse, big displacement or separation of floor tiling panel, breakage of floor panel > 2mm, there is big change of protection rock.
Crack on concrete and	I	0-40	The best safety condition and there is not crack at concrete and damage in reinforced panel.

Factor	Levels of safety	Score	Description of safety related factors to safety of drainage canal after overflow weir
damage to reinforce	II	41-70	Condition are affected little because ofseveral small concrete cracks and small damage in reinforced panel
	III	71-100	Safety condition is at risk because ofwidth of concrete crack > 1mm and depth of concrete crack > 15cm to reinforced panel
Damage and degradation of side wall	I	0-40	The best safety condition and there is damage and degradation of side wall
	II	41-70	Condition are affected little because of there are several small demages and degradation at side wall but not dangerous
	III	71-100	Safety condition is at risk because of breaking at connection section> 2mm and serious degradation such as crack and leakage.
Damage at transient sections into absortion equipments	I	0-40	The best safety condition , no damage at transient section
	II	41-70	Condition are affected little and there is leaking transient section < 4 *l*/minute. There is damage affecting safe working condition of transmission section
	III	71-100	Safety condition is at riskbecause ofleakage at transient section > 75 *l*/minute. Or there is damage affecting safe and effective working condition, of transient section.

Table 8. Criteria and scoringscoring of safety related factors to safety of absortion equipments

Factor	Levels of safety	Score	Description of safety related factors to safety of baffle equipments
Peeling and cavity of baffle equipments	I	0-40	The best safety condition because ofphenomenon of peeling and cavity of absortion equipments.
	II	41-70	Medium condition because ofpeeling and cavity at diameters and depth < 0.15 mm.
	III	71-100	Safety condition is at risk because ofpeeling and cavity at baffle equipment at diameter and depth > 0.15 mm.
Aggrading acour at downstream of baffle equipment	I	0-40	The best safety condition because of not aggrading scour at the downstream of baffle equipments.
	II	41-70	Condition are affected little because that there is small aggrading scour at the downstream of baffle equipment but not dangerous.
	III	71-100	Safety condition is at riskbecause ofaggrading scour at downstream of baffle equipment (crack width of connection section > 5mm, inclination of side wall > 10°).
Damage at work item	I	0-40	The best safety condition and there is not damged in work item with absortion equipments.

relating to baffle equipment	II	41-70	Condition are affected little because there are some damges in work item relating to baffle such as settlement, collapse, crack, breaking, etc.
	III	71-100	Safety condition is at risk because there are many damage at work item relating to absortion.
Scour near the bottom of baffle equipment and side wall	I	0-40	The best safety condition and there is not scour near the bottom of apsortion equipments and side wall
	II	41-70	Condition are affected little because of scour at the bottom of baffle equipment and side wall but not dangerous.
	III	71-100	Safety condition is at risk because of scour near the bottom of baffle equipment and side wall with depth > 0.15m.

Table 9. Criteria and scoringscoring of safety related factors to safety of intake projects

Factor	*Levels of safety*	*Score*	*Description of safety related factors to safety of intake project*
Crash or displacement of intake tower	I	0-40	The best safety condition because of not crash and displacement of intake tower.
	II	41-70	Condition are affected little because of crash and displacement of intake tower but not dangerous
	III	71-100	Safety condition is at risk because of crash and displacement of intake gate of intake tower (inclination > 5°).
Decrease intake volume and difficulty in water intake	I	0-40	The best safety condition because of no effect on intake volume and no difficulty in intaking water.
	II	41-70	Safety are affected little because of effect on water intake volume and difficulty in water intake.
	III	71-100	Safety condition is at risk because of affecting water intake volume and difficulty in water intake.
Corrosion of damping system and stability of structure	I	0-40	The best Safety because of no corrosion of damping system and affecting on stability of structures.
	II	41-70	Safety is affected little because of corrosion of damping system and affecting the stretch on stability of structures, but not dangerous.
	III	71-100	Safety condition is at risk because of corrosion at damping system and affecting the stretch.
Scour at banks and slope	I	0-40	The best safety condition because ofof no scour at bank and slope.
	II	41-70	Safety is affected little because of scour at bank and slope.
	III	71-100	Safety condition is at risk because of too many scour

Factor	Levels of safety	Score	Description of safety related factors to safety of intake project
			phenomenons at banks and slope

Table 10. Criteria and scores of related factors to safety of concrete items in general

Factor	Levels of safety	Score	Description of related factors to safety of concrete items in general
Neutral	I	0-40	The status of not neutral
	II	41-70	Thickness of protection layer > neutral depth ≥ Half of protection layer's thickness Thickness of protection layer ≥ 40mm.
	III	71-100	Thickness of protection layer > neutral depth ≥ half of protection layer's thickness. Thickness of protection layer < 40mm.
Concentration of Clorua	I	0-40	Clorua ≤ 0,15 kgf/m^3.
	II	41-70	0,3 kgf/m^3 < Clorua ≤ 0,6 kgf/m^3.
	III	71-100	0,6 kgf/m^3 < Clorua ≤ 1,2 kgf/m^3.
Crack	I	0-40	Status is solid and not crack
	II	41-70	Length of crack 1-5m, width of crack is 0,5-2mm, Depth of crack is 15-30cm, there are 1-3 cracks, crack area 2-5m^2.
	III	71-100	Worried status shows out that the project is losing its functions because of serious cracks on whole project. (Length of crack ≥ 5m, width of crack is ≥ 2mm, Depth of crack is ≥ 30cm, there are more than 3 cracks, exposed steel, crack area ≥ 5m^2).
Alternation	I	0-40	There is not alternation.
	II	41-70	Area of alternation area is from 5-10%, quantity of 2-10 seats, area ≤ 2m^2 and light intensity decline.
	III	71-100	There is serious alternation, alternation area > 10%, quantity > 10 seats, area > 2m^2.
Inclination, displacement and settlement	I	0-40	There is no inclination, settlement, displacement
	II	41-70	There is inclination, displacement, small settlement, not over allowed limit.
	III	71-100	There is inclination, displacement and settlement over allowed limit
Exposed steel	I	0-40	Rate of exposed steel is 0%.
	II	41-70	Rate of exposed steel is from 0÷3%, positions of exposed

Factor	*Levels of safety*	*Score*	*Description of related factors to safety of concrete items in general*
			steel 1-2, area < 0,5m^2, there are impacts on internal changes
	III	71-100	Rate of exposed steel > 3%, positions of exposed steel > 2, area > 0,5m^2, there are impacts on internal changes
Leakage	I	0-40	There is not leakage
	II	41-70	There is leakage (wet leakage).
	III	71-100	Considerable leakage (leakage through cracking joint > 19 *l*/minutes).
Crack and damage	I	0-40	There is crack and damage.
	II	41-70	Depth of brakage and small damage smaller than 5mm and area rate ≥ 10% or 5÷10mm and area rate < 10%.
	III	71-100	Depth of brakage and damage bigger than 5mm or breakage area ≥ 10%.

8.3. Process of rapid assessment

With complex head works of reservoir capacity smaller than 10 million m^3, the process of rapid assessment on safety includes the following steps:

- Step 1: Collect basic datas and documents;
- Step 2: Investigate, survey for safety assessment of each work item;
- Step 3: Score and assess the safety of each work item according to scoring rank in item 8.2;
- Step 4: Assess generally safety of project complex;
- Step 5: Conclude the safety situation and propose solutions for safety enhancement.

8.4. Contents of each steps in rapid assessment process

8.4.1. Step 1: Collect basic datas and documents

Some documents should be collected as the base for current status assessment including design documents, documents of execution process, operation, repairing, upgrading. Some specific documents are as follows:

- Statements on scope, maner, arrangement, components of work items such as dam, overflow, intake sewer, etc.
- Drawings of plan, vertical and horizontal sections and components of each item of the reservoir;
- Documetns of project's operation and exploitation process;
- Documetns about annual maintenance process of the project;
- Documents about damages (if any).

8.4.2. Step 2: Investigate, survey actual geology and assess safety of each work item

The site investigation and surveying is very important step in order to assess the safety of the project. Methods of collecting information can be performed according to method of assessment by visual, taking photographs with high resolution or measurements by some simple surveying equipment such as meter rules or methods of information collection. Contents of information collection should be based on assessment and scoring criteria as mentioned at item 8.2.

8.4.3. Step 3: Score and assess safety of each work item

Information of project's current status collected from stage 2 is used to assess safety level of each work item and score. As a base for scoring and safety assessment of eath work item, there are some design data of the project collected at stage 1 and contents of scoring criteria as mentioned at item 8.2. The assessment and scoring of safety to each work item can be carried out at the site coinciding with information collection or carried out in the room after collecting information about project's current status symetically.8.4.4. Step 4: General assessment of complex head works'

Safety of the complex head works with earthfill dam is integrated safety assessment of earthfill dam, spillway, intake items and other concrete items. In order to carry out this step, some contents should be performed in turn:

1. Assessment of earthfill dam's safety

The safety of earthfill dam is evaluated (table 15) from general safety assessment of dam crest (table 11), upsteam face (table 12), downstream roof (table 13), foundation and two abutments (table 14).

Table 11. Safety assessment of dam crest

Factor	***Level of safety***	***Assessment score***	***Assessment coefficient***	***Assessment indicator***
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Vertical/ horizontal crack				
Settlement				
Horizontal displacement				
Damages of wave barrier wall				
Slope of dam crest				
+ Assessment indicator of dam crest's current status (E_1):				
+ Grade (scoring) of dam crest's current safety status:				

Instruction to develop table 11:

+ Column (1): factors should be assessed to determine the safety of dam crest (actually specific criteria);

+ Column (2), (3): determined according to corresponding sections from Table 2 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4).

+ Assessment indicators (score) of the current status of the dam's crest (E_1) is the maximum value of assessment indicators of each item.

+ Ranking the safety level of the dam's crest according to the table 1 using the value E_1

Table 12. Safety assessment of upstream face

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Penetration from dam body				
Settlement and deformation				
Damages in anti-leakage equipments				
Stability of slope and slope protection				
Upstream face erosion				
+ Assessment indicator of upstream face's current status (E_1): *+ Grade (scoring) of upstream face's current safety status:*				

Instruction to develop table 12:

+ Column (1): factors should be assessed to determine the safety of upstream dam's face (actually specific criteria);

+ Column (2), (3): determined according to corresponding sections from Table 3 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4).

+Assessment indicators (score) of the current status of the upstream dam's face (E_1) is the maximum value of assessment indicators of each item.

+ Ranking the safety level of the upstream dam's face according to the table 1 using the value of E_1

Table 13. Safety assessment of downstream face

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Penetration from dam body, status of water drainage equipments				
Slope stability				
Downstream face protection equipment				

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Scour at downstream face				
Plant carpet				
Cave, animal nest				
+ Assessment indicator of downstream face's current status (E_1):				
+ Grade (scoring) of downstream face's current safety status:				

Instruction to develop table 13:

+ Column (1): factors should be assessed to determine the safety of downstream dam's face (actually specific criteria);

+ Column (2), (3): determined according to corresponding sections from Table 4 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4).

+ Assessment indicators (score) of the current status of the downstream dam's face (E_1) is the maximum value of assessment indicators of each item.

+ Ranking the safety level of the downstream dam's face according to the table 1 using the value of E_1

Table 14. Safety assessment of foundation and two abutments

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Settlement and collapse at partly component of foundation and abutment				
Scour and penetration at foundation and abutment				
+ Assessment indicator of foundation and two abutments' current status (E_1):				
+ Grade(scoring) of foundation and two abutments' current safety status:				

After evaluating each component of the dam, carry out safety assessment of the dame as in the table 15.

Instruction to develop table 14:

+ Column (1): factors should be assessed to determine the safety of dam's foundation and two abutments (actually specific criteria);

+ Column (2), (3): determined according to corresponding sections from Table 5 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4).

+ Assessment indicators (score) of the current status of the dam's foundation and two abutments (E_1) is the maximum value of assessment indicators of each item.

+ Ranking the safety level of the dam's foundation and two abutments according to the table 1 using the value of E_1

Table 15. General assessment of the dam

Component	*Level of safety*	*Assessment indicators (E_1)*	*Factors of adjustment (A)*	*Weighting (W, %)*	*Caculation value A.W*	*Caculation value E_1.A.W*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Dam crest						
Upstream face						
Downstream face						
Foundation and two abutments						
Total				100		
+ Assessment indicator of dam's current status (E_2): *+ Grade (scoring) of dam's current safety status:*						

Attentions should be paidwhen developing table 15:

+ Value at column (2), (3): taken according to assessment table of each component;

+ Column (4): Coefficient of Adjustment factor to assess the importance level of each component as compared to the dam; Considering that A=2 for items: dam crest, upstream dam's face, foundation and two abutments; A=3 for downstream dam's face

+ Column (5): Weight has total of 100 distributed for components;

+ Column (6): Value by column (4) multiplying with column (5);

+ Column (7): Value by column (6) multiplying with column (3);

+ Indicator (score) of dam's general assessment is:

$$E_2 = \frac{\sum E_1.A_i.\mathrm{W}_i}{\sum A_i.\mathrm{W}_i} \qquad (1)$$

+ Grade of dam's current safety under guidelines at table 1.

2. Safety Assessment of spillway

Assess each component according to tables (16), (17), (18) and assess generally through table (19) with attentions that table should be made similarly to assessment of earthfill dam

Table 16. Safety Assessment table of outlet works and spillway

Factor	***Level of safety***	***Assessment score***	***Assessment coefficient***	***Assessment indicator***
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Damages on the face of concrete and steel structure				
Stability of side wall				
Stability of canal bank's slope.				
Plant carpet and barriers in *outlet work and spillway*				
+ *Assessment indicator of outlet works and spillway's current status (E_1):* + *Grade (scoring) of intake canel and overflow weir's current safety status:*				

Instruction to develop table 16:

+ Column (1): should be assessed to determine the safety of dam's outlet works and spillway (actually specific criteria);

+ Column (2), (3): determined according to corresponding sections from Table 6 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4)..

+ Assessment indicators (score) of the current status of the dam's outlet works and spillway (E_1) is the maximum value of assessment indicators of each item.

+ Ranking the safety level of the dam's outlet works and spillway abutments according to the table 1 using the value of E_1

Table 17. Safety assessment of drainage canal afer spillway

Factor	***Level of safety***	***Assessment score***	***Assessment coefficient***	***Assessment indicator***
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Settlement, displacement and stability of canal protection equipment				
Crack on concrete and damages at reinforce				
Damages and degradation at side wall				

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Damages at transient section to stilling basins				
+ *Assessment indicator of drainage canal's current status (E_1) after spillway:* + *Ranking(scoring) of discharge outlet's current safety status:*				

Instruction to develop table 17:

+ Column (1): should be assessed to determine the safety of drainage canal (actually specific criteria);

+ Column (2), (3):): determined according to corresponding sections from Table 7 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4)..

+ Assessment indicators (score) of the current status of the dam's drainage canal after the spillway (E_1) is the maximum value of assessment indicators of each item.

+Ranking the safety level of the dam's canal after the spillway abutments according to the table 1 using the value of E_1.

Table 18. Safety assessment of Stilling Basin

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Decay and cavity in Stilling Basin				
Erosion at the downstream of Stilling Basin				
Damages in structures relating to Stilling Basin				
Erosion near the bottom of Stilling Basin and side wall				
+ *Assessment indicator of* Stilling Basins' *current status (E_1):* + *Ranking (scoring) of* Stilling Basin*'s current safety status:*				

Instruction to develop table 18:

+ Column (1): should be assessed to determine the safety of Stilling Basin (actually specific criteria);

+ Column (2), (3): determined according to corresponding sections from Table 8 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4).

+ Assessment indicators (score) of the current status of the dam's Stilling Basin ($E_{1)}$ is the maximum value of assessment indicators of each item.

+ Ranking the safety level of the Stilling Basin according to the table 1 using the value of E_1.

Table 19. Comprehensive safety assessment of the spillway

Component	***Level of safety***	***Assessment indicators (E_1)***	***Factors of adjustment (A)***	***Weighting (W, %)***	***Caculation value A.W***	***Caculation value E_1.A.W***
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Outlet work and spillway						
Discharge channel behind the spillway						
Stilling Basin						
Total				100		
+ Assessment indicator of the spillway's current status (E_2): *+ Ranking(scoring) of spillway's current safety status:*						

Instruction to develop table 19:

+ Value of Column (2), (3): Using the assessment value of each item/component) in Table 16, 17, 18;

+ Column (4): Coefficient of Adjustment factor to assess the importance level of each component/item of the spillway structure; Considering A=2 for: Outlet work and spillway, drainage canal after the spillway; A=3 for the Stilling Basin.

+ Column (5): Weight has total of 100% distributed for components of the spillway dam structure; Considering W=30% for: outlet works and spillway, as well as drainage canal; W=40% for Stilling Basin.

+ Column (6): results of column (4) multiplying with column (5);

+ Column (7): results of column (6) multiplying with column (3);

+ (score) overall assessment of the dam's current status as E_2 is calculated using formula (1)

+ Assessment indicators (score) of the current status of the spillway according to the instruction of table 1 using the value E_2 calculated by formula (1).

3. Safety assessment of the Outlet work and other concrete structures

Assess each component of the outlet work and other concrete structures according to the Table 20 and 21, then based on that develop an overall assessment of table 22 with similar cautions to the tables for safety assessment of earthfill dam.

Table 20. Safety assessment of outlet works

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Breach and displacement of outlet works				
Reduce intake volume and difficulties in water intake				
Erosion in damping system and and the durability and stability of structure				
Erosion in the embankment and slope				
+ Assessment indicator of outlet work's current status (E_1): *+ Ranking(scoring) of outlet work's current safety status:*				

Instruction to develop table 20:

+ Column (1): should be assessed to determine the safety of the outlet works (actually specific criteria);

+ Column (2), (3): determined according to corresponding sections from Table 9 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4)..

+ Assessment indicators (score) of the current status of the dam's outlet work (E_1) is the maximum value of assessment indicators of each item.

+ Ranking the safety level of the Outlet work according to the table 1 using the value of E_1.

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Table 21. Safety assessment of other concrete structures

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Neutralization				
Concentration of Cloride				
Crack				

Factor	*Level of safety*	*Assessment score*	*Assessment coefficient*	*Assessment indicator*
(1)	*(2)*	*(3)*	*(4)*	*(5)*
Wind erosion				
Inclination, displacement, settlement				
Exposed reinforce structure				
Leakage/seepage				
Breakage and damage				
+ Assessment indicator of other concrete structure's current status (E_1): *+ Ranking (scoring) of other concrete structure's current safety status:*				

Instruction to develop table 21:

+ Column (1): should be assessed to determine the safety of other concrete structures (actually specific criteria);

+ Column (2), (3 determined according to corresponding sections from Table 10 using the actual description of each factor;

+ Column (4): Depending on each dam, there are assessment coefficients. Actually, it is the level of importance of assessed items. The assessment coefficients of each item can be the same and equal to 1

+ Column (5): results of column (3) multiplying with column (4).

+Assessment indicators (score) of the current status of other concrete structure (E_1) is the maximum value of assessment indicators of each item.

Ranking the safety level of other concrete structures should follow the table 1 using the the existing value of E_1.

Table 22. General safety assessment of outlet works and other concrete structures

Component	*Level of safety*	*Assessment indicators (E_1)*	*Factors of adjustment (A)*	*Weighting (W, %)*	*Caculation value A.W*	*Caculation value E_1.A.W*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Outlet works						
Other concrete structures						
Total				100		
+ Assessment indicator of intake item and other concrete structure's current status (E_2): *+ Ranking(scoring) of outlet work and other concrete structure's current overall safety status (according to table 1)*						

Instruction to develop table 22:

+ Column (1) are names of each items/components of the outlet works or other concrete structure. The number of intake structure can be equal to one or more. The number of other structures can be equal to one or more.

+ Value of Column (2), (3): Using the assessment value of each item/component) in Table 20, 21;

+ Column (4): Nhân Coefficient of Adjustment factor to assess the importance level of each component/item of the outlet works and other concrete structures. Considering A=2 for outlet works and other concrete structures.

+ Column (5): Weighting have the total value of 100% is divided into different items (components. Considering that W is the same for each item. For example, 2 outlet works, 3 other concrete structure, that mean the total number of items (structures) is 5. Therefore, if the W is the same for each structure, W=20%

+ Column (6): results of column (4) multiplying with column (5);

+ Column (7): results of column (6) multiplying with column (3);

+ Chỉ số (điểm) đánh giá chung hiện trạng của công trình lấy nước và các công trình bê tông khác là E_2 tính theo công thức (1)

+ Assessment indicators (score) of the current status of outlet works and other concrete structure using the instruction of table 1 with the value E2 calculated by formula (1).

4. Overall assessment

From assessment results of each item and component, carry out overall safety assessment of key dam's complex according to Table 23.

Table 23. Overall safety assessment of the dam complex

Component	***Level of safety***	***Assessment indicators (E_1)***	***Factors of adjustment (A)***	***Weighting (W, %)***	***Caculation value A.W***	***Caculation value E_1.A.W***
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Dam body						
Spillway						
Outletworks and other concrete structures						
Total				100		
+ Assessment indicator of key dam complex's current status (E_3): *+ Grade(scoring) of key project complex's current safety status:*						

In table 23, some attentions should be paid:

- Column (1): Components of the dam/reservoir;
- Column (2), (3): Take results from assessment of each above item(E2);

- Column (4): Adjustment coefficient A is selected depending on importance level of each component to the overall safety (for more important ones) it is possible to take similar value A=2;

- Column (5): weight indicates the impacts of each individual structure on the safety of the whole dam complex. For example, we can consider W=40-60% for the dam body structure, W=50-20% for spillway, and W=10-20% for outlet works and other concrete structures

- Column (6): is column (4) multiplying with column (5);

- Column (7): is column (3) multiplying with column (6);

- Overall assessment indicator of key dam structures:

$$E_3 = \frac{\sum E_2 . A_i . \mathrm{W}_i}{\sum A_i . \mathrm{W}_i} \tag{3-2}$$

- Ranking of safety level of key dam structures.

8.4.5. Step 5: Conclusion on safety level and proposing solutions to ensure safety of the structures

The assessment results at step 4 indicates the safety level of the dam's complex. In particular, there are three levels:

- High safety level or low risk of dam failure when: E_3 = 0-40 points;

- Safety level or medium risks of dam failure when: E_3 = 41-70 points;

- At risk of losing safety level or high risk dam failure when: E_3 = 71-100 points;

Based on these safety levels, the dam operation authorities will determine suitable solutions:

- At the level of losing dam's safety (high risk of dam failure): In this case, it is required to have urgent measures to enhance safety level (reduce risk of dam failure). That means to quickly apply one or a combination of many methods: lower water level in the reservoir, strengthen the dam slope, heighten the dam crest; treatment for settlement, resettling the downstream area, etc;

- At the level of appropriate dam's safety (medium risk of dam failure). At this level, it is required to imporve the monitoring and pepare suitable solutions according to each possible scenario during the time of heavy rain, storm or high water level in the reservoir;

- At the level of high dam's safety (low risk of dam failure). In this case, the manager should not take it for granted, and still need to continue the management, monitoring and inspection activities, etc , according to current technical requirements, regulations and legal documents.

References:

1. Pham Ngoc Quy and nnk (2016) - Criteria of earthfill dam's safety assessment – Civil engineering publishing house, Hanoi