XL Risk Consulting

Property Risk Consulting Guidelines

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DAMS AND OTHER HYDRAULIC STRUCTURES

INTRODUCTION

The purpose of a dam evaluation is to review the design, construction and performance history of the dam and associated structures, and evaluates their structural integrity. The effective control and utilization of stored water is the obvious basis of operation of hydroelectric power generation, thus reservoir operation is also important in evaluating the overall integrity of the project. The dam, spillways and outlet works, other appurtenant structures, embankments, the reservoir rim and reservoir operation as well as the powerhouse structure need to be surveyed. Electrical generating equipment will be surveyed under other loss prevention guidelines.

Regional watershed flow characteristics and upstream flow control structures are important in design considerations. They also affect the loss potential of a power project.

POSITION

Conduct regular self-inspections of hydraulic structures directed toward identifying potentially damaging conditions. Include in the inspections a review of site inspection, maintenance and instrumentation records. These records identify changes in conditions and highlight areas of potential distress.

Loss Prevention Surveys at the site will require visual examination of the existing condition and review of data from instrumentation monitoring to identify changes in conditions and signs of distress. Also review maintenance records and note unusual repair.

BACKGROUND

The “Power Project” physical arrangement consists of three major entities:

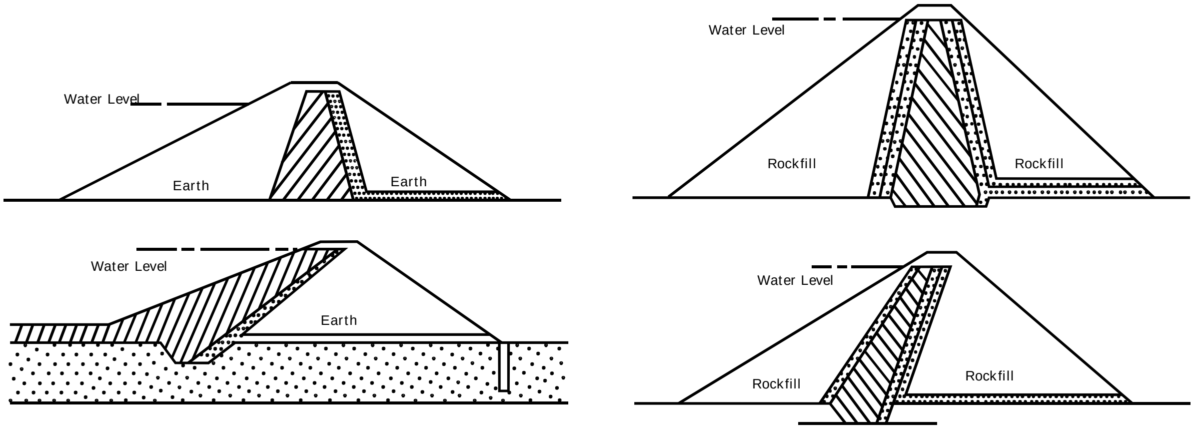
- Water control, impoundment and distribution structures;
- Power generating structures;
- Electric substation and transmission equipment.

Modern dams may be designed and constructed to control or withstand a probable maximum flood (PMF) of the watershed area. Earlier constructed projects will have a current hydrologic analysis report indicating safe flood elevation. Since dams are water flow control structures; it is generally presumed that associated structures are not subject to flood. However, a number of unusual circumstances may inadvertently cause flooding. For example, the unusual condition of logjam on the upstream side of the dam crest can raise the reservoir and upstream water elevation to above safe flood levels. A downstream obstruction can cause water backup into the dam tailrace.

In addition to the threat of unusually high water levels are the long-term effects of water acting upon the soils of the embankments, constructed facilities and dam works foundations.

The design of a dam will usually fall into one of the four basic categories with local condition requirements causing a variation of or a combination of these. Stability against abnormal load conditions such as flood, ice or earthquake is required for all dams. Small dams of steel, timber or crib design, and small impoundments of other types are not considered in this general discussion.

- **Embankment Dam**: Some literature may refer to any dam constructed of excavated earth materials such as sand, sand gravel or soils as a fill dam. As the name implies, material is filled or placed to create mass with sloping sides. Upstream and downstream dam faces of embankment dams are both sloping. Variations on this concept utilize different materials that might be rock, earth, rolled earth or hydraulically placed fill. All require "sealing" against seepage with an impervious section, zone or core. Examples of embankment dams are shown in Figure 1.



Earth Fill Type **Rock Fill Type**

Figure 1.[1] Embankment Type.

- **Gravity Dam**: A dam constructed of concrete or masonry (quarried rock) units that relies upon its weight for stability against overturning or sliding. Variations of modern design may include arch, curve or cellular (hollow) styles. A sketch of gravity type designs is shown in Figure 2.

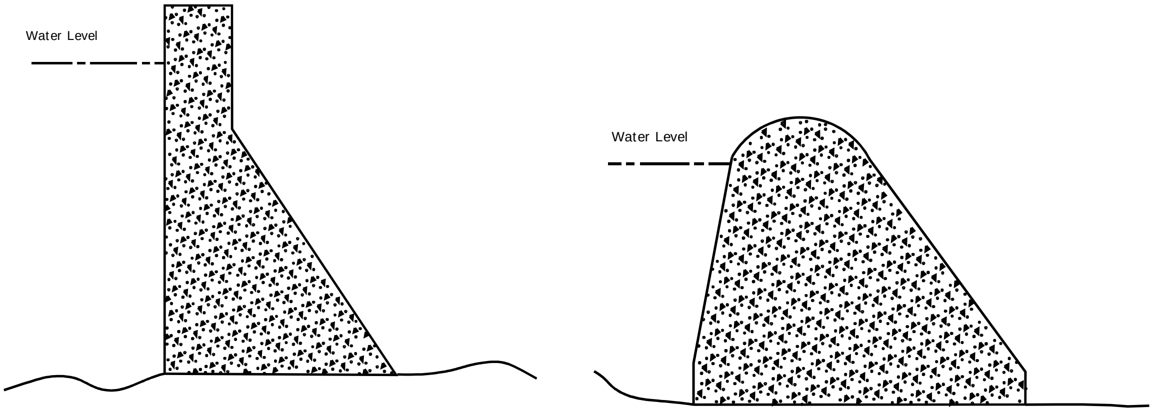


Figure 2. Gravity Type.

- **Buttress Dam**: A concrete or masonry dam consisting of a watertight, upstream face supported at intervals on the downstream side by a series of buttresses. Variations of this design may include: curve; multiple arches; solid head; flat slab (Ambursen or Deck Dam); or prestressed. Figure 3 is a flat slab buttress design.

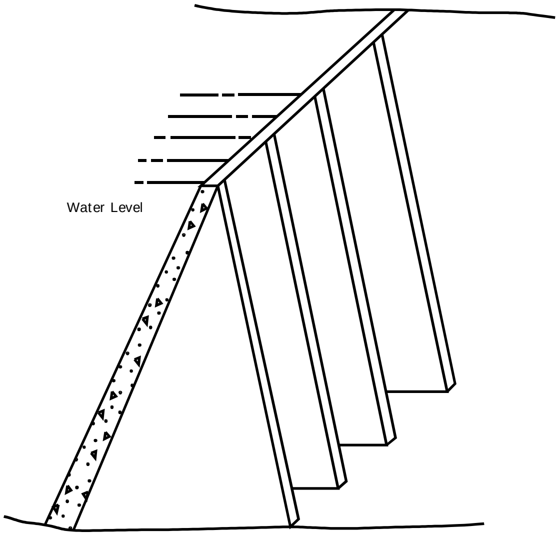


Figure 3. Flat Slab – Buttressed.

- **Arch Dam**: A concrete or masonry dam that is curved in plan so as to transmit the major part of the water load to the abutments. Variations on this design usually involve shape and load bearing element alterations. An example of an arch dam is shown in Figure 4.

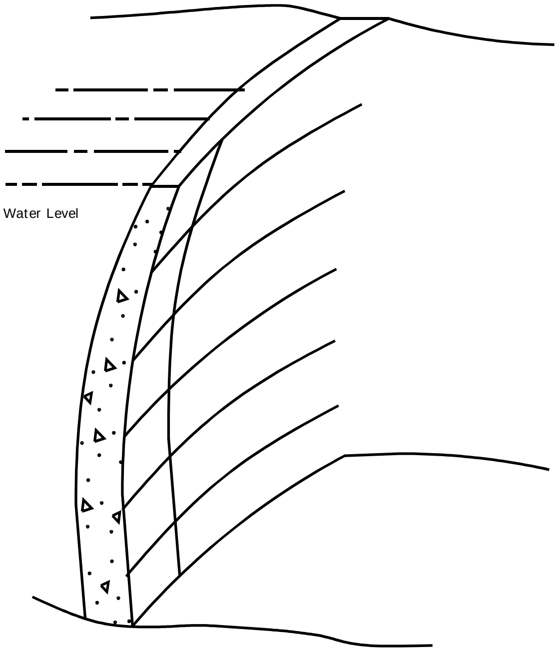


Figure 4. Arch Type.

Regardless of dam type and style, design considerations must account for load conditions during operation, maximum flood, wind and wave, ice, seiche and earthquake that may act to erode, breach, overturn or slide the dam. Extensive investigative studies are necessary in choosing a dam site. Ground preparation may require modification of the profile of underlying earth, rock or both to stabilize the foundation. Stability, bearing strength and water tightness are basic criteria for foundation and abutment walls of the proposed site. Figure 5 illustrates seepage paths under a central core dam. Inasmuch as water will be an attendant addition to the geologic environment, its effects must be assessed.

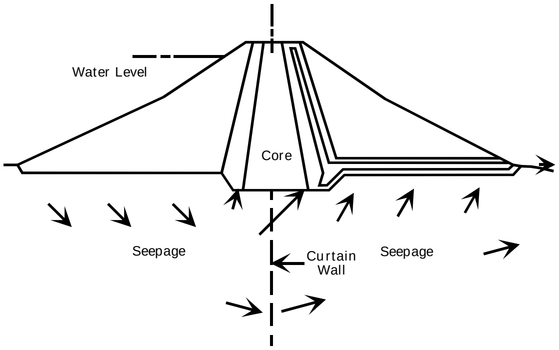


Figure 5. Central Core Seepage.

Visual and instrumentation monitoring of the foundation and structure is necessary to assess the continued integrity of the project. Such conditions as uplift, settlement, seepage, drainage and movement need to be monitored and evaluated in a continuing program. The purpose of instrumentation is to furnish data that can be used to determine if the structure is maintaining its integrity and stability as intended, and to provide a continuous surveillance of the structure to warn of developments which endanger its safety.

DAM FAILURE

Dam failures due to geologic or construction defects have occurred at projects during construction, immediately following construction, and at some time after the reservoir was filled. The Waco Dam in Texas failed in 1961; construction of the embankment was within 13 ft (4.0 m) of finished elevation. The Teton Dam in Idaho failed in 1976 while the reservoir was being filled immediately following completion of construction. The Baldwin Hill Reservoir in California failed in 1963, 12 yr after the reservoir was filled. The Malpasset Dam in France failed 5 yr after completion; however, the failure was coincident with the first reservoir filling to the spillway crest. This failure was significant since it was the first in the history of arch dams. Each of these failures was attributed to the effects of water upon the site geologic environment.

A number of studies have been made of dam failures and accidents, and substantial statistics generated. Several items of interest regarding dams of the United States and Western Europe follow.

There has been a progressive improvement (decrease) in the rate of dam failures for structures constructed over the period 1900 to 1975 according to the International Commission of Large Dams (ICOLD) and the United States Commission of Large Dams (USCOLD)[2] now know as United States Society on Dams. Embankment dams built in the 1900 era have a 10% probability of failure. Comparable aged gravity dams (concrete) have a 6.5% probability of failure. Dams built in the 1930 era perform significantly better with only a 1% probability of failing; and “modern” dams (constructed from the 1950s on) have less than a 0.04% probability of failure. The probability decreases logarithmically. Dams over 30 yr old have a significantly higher risk of failing than do modern dams. Older embankment dams have a higher risk of failure than do concrete types. Dams that have been in service for an extended length of time are not immune to failure. Some failures may take years to develop. Changes in conditions need to be monitored; the structural behavior of a dam is dynamic and has a history.

CAUSES OF FAILURE

In a USCOLD report published jointly with the American Society of Civil Engineers in 1975, the following were some of the major causes of failure. Failure was considered when water was released downstream.

- Overtopping has caused 26% of the failures but 13% of all incidents. The principal reason for overtoping was inadequate spillway capacity. Overtopping of earth embankment dams leads to surface erosion and failure. Overtopping of concrete dams and masonry dams does not necessarily cause failure. In one incident of overtopping involving a concrete structure, the powerhouse and electrical equipment were damaged, but not the dam.
- Water seepage, leakage or internal channeling (piping) of embankment dams led to total breaching in 22% of all failures and 13% of all incidents. Water seepage is the principal causes of failure in embankment type dams.
- Foundation seepage, leakage or internal channeling is believed to be responsible for 17% of the failures and 24% of all incidents. This was the number one cause of all incidents. There was twice the amount of embankment type dam failures then concrete gravity type failures.
- Channel erosion caused 17% of the failures and 12% of all incidents. Of these failures 82% involved embankment dams where the spillways failed. The remainder involved various structure washout or undermining of dams.
- Sliding accounted for 6% of the failures and 12% of all incidents. Sliding was related to instability in the foundation, embankments or abutments. In one failure, a concrete gravity structure slid 18 in. (457 mm) downstream. Before repair and remedial measures could be taken, the reservoir was refilled and the load caused large sections of the dam to overturn or slide open like a door.
- The remaining failures are due to deformation, deterioration, faulty design or construction, gate failures or other miscellaneous causes. There were incidents of damage due to earthquake instability in which two of the dams required complete reconstruction.

Failure Mechanisms

Indicators of project stress are seen as changes in physical conditions such as increased pore pressures, increased see pages, heavy drainage, piping (internal channeling), bank erosion, soil saturation, landsliding, settlement, vertical tilting, or other displacements and undermining of the dam or associated structures, foundation or reservoir. Concrete deterioration is significant for concrete constructions. Soil saturation is particularly important in the reservoir banks and perimeter slopes where wave action or unstable slopes can cause slumping, landsliding and sedimentation.

Structure

- Water leakage, seepage, internal channeling and erosion are indicated by wet spots, boils or other evidence of pressure flow, leaching, channelization and gully formation, sinkholes, soft spots, local settling, marsh-type vegetation and unexplained soil loss.
- Heavy drainage can be caused by cracked, deteriorated or porous concrete, leaking tunnels and penstocks or internal sediment washout and channeling.
- Stress and strain cause cracking, crushing, displacement, offsets, creep, bending, buckling, subsidence and heaving.
- Instability causes tilting, tipping, sliding and overturning.

Reservoir

- Pool stage changes, whirlpooling, depressions and sinkholes in the basin surface suggest heavy drainage or channeling in the reservoir foundation.
- Leaning trees, hillside distortions, escarpments, pool encroachment, silting, channel approach obstructions and bank wetness suggest landslide potential.

Watershed

- Upstream headwater and river bank changes might affect regional precipitation runoff rates.
- River channel and bank changes might affect reservoir inflow volume and rate, and spillway discharge characteristics.

Tilt meters, strain meters, piezometers, seismometers and weirs are common devices used for monitoring the dynamic structural behavior of a hydraulic structure. The extent and nature of instrumentation depends upon the project design, dam type, size of the impoundment, and the complexity of the geologic environment.

Project Evaluation

Where a first survey is undertaken or a more thorough evaluation of the overall project is desired, greater detail and a broader scope of information is required. Following is a summary of data which should be provided to the authority responsible for review and evaluation.

Location

- State, country and nearby city or town;
- Name of river or body of water;
- Mile point location on river course;
- Elevation and reference datum (i.e., sea level or other);
- Site plan and topographic quadrangle map which includes site.

Dam

- Type and year of construction;
- Operating category (i.e., single dam, one of a series on the same water course, one of a group on converging waterways);
- Design criteria (height, width, drainage area, run off, design inflow-outflow, reservoir size area and elevation full, draw down, freeboard, foundation treatment, spillway capacity, safety devices);
- General condition with record of inspection;
- Seepage with record of monitoring and stability study;
- Structural behavior with records of monitoring;
- Seismic zone of site and hazard design with records of seismic monitoring or activity;
- Design flood analysis referring to 100 yr frequency and PML (probable maximum flood);
- Dam break flood analysis and inundation map;
- Emergency action plan.

Water power projects are required to be licensed by the federal government and are inspected and examined by the Federal Energy Regulatory Commission, usually on an annual basis. In addition, the licensee must provide an in-depth comprehensive safety evaluation conducted by an independent engineering consultant on a 5 yr schedule. State agencies also may make periodic inspections and reports of inspection are provided to the licensee.

When a first survey involves a FERC licensed project, the original plus the most current FERC Reports will usually provide adequate information for AXA XL Risk Consulting project elevation. Copies of these reports should be requested.

REFERENCES

1. Figures 1 thru 5 adapted from Corps Of Engineers, *U.S. Army, Engineering And Design Manuals* Series, EM 1110-2-2200, EM 1110-2-2300.

2. *Lessons From Dam Incidents*, USA 1979 Transaction of ICOLD Congress, New Delhi available through American Society of Civil Engineers, Reston, VA.