WILL YOU BE ABLE TO ACCESS YOUR DAM DURING EMERGENCIES?

Jeffrey Racicot, P.E.[1]
David Lord, P.E.[2]

ABSTRACT

Project staff's ability to respond to an emergency is a reflection of emergency preparedness. One component of emergency preparedness is assuring the ability to access your project in an emergency. Access to the project means the ability of project staff to reach the project during normal and adverse conditions in order to operate equipment and inspect project structures and the ability to transport emergency equipment and supplies to the project during emergencies. In addition, access is essential for assessing the seriousness of uncontrolled releases of water and coordinating the post-failure response and evacuation. Will access to your project be denied or seriously affected by a flood or storm condition that may prevent trained project staff from doing their jobs during an emergency? Can staff access the dam for local operation of spillway or sluice gates? Can necessary supplies and equipment be delivered to your project during emergency situations? Alternate access to dams during emergencies, which can potentially reduce the risk of dam failure and reduce the consequence to the population at risk, should be well understood and incorporated into all dam safety programs and emergency action plans. The emphasis should focus on primary and alternate routes, and means for reaching the dam under various conditions. The expected times to travel the primary and alternate access routes during emergency situations should be well understood by project staff and emergency action plan (EAP) coordinators.

We discuss: case studies that illustrate where project staff were unable to access their project during emergencies, what constitutes a credible risk reduction suggestion, how to integrate project access with potential failure modes, emergency planning, and the owner's dam safety program.

INTRODUCTION

Access to the critical components of a dam at any time is essential. Access to the dam means the ability of project staff to reach the project during normal and adverse conditions in order to operate equipment and inspect project structures and the ability to transport emergency equipment and supplies to the project during emergencies. Access in an emergency provides the ability to visually monitor the dam, assess the seriousness of uncontrolled releases of water and to coordinate the post-failure response and evacuation. Dam owners spend time and resources to train staff to understand standard operating procedures during normal and emergency conditions. However, consideration of whether or not the highly trained staff can get to the dam at all times to do their job is

[1] Civil Engineer, FERC, Division of Dam Safety and Inspections, Portland Regional Office, 503-552-2738; Jeffrey.Racicot@FERC.gov
[2] Senior Civil Engineer, FERC, Division of Dam Safety and Inspections, Portland Regional Office, 503-552-2728, david.lord@ferc.gov

often overlooked. In light of increasing trends towards remote operation of projects dam owners should evaluate how long it will really take for project staff to get to their dams under realistic conditions. This paper provides examples of when to evaluate emergency project access, specifically during the potential failure mode analysis, emergency action planning, review of the ODSP, and regular site inspections.

CASE STUDIES

Lessons learned from the following case studies reinforce the importance of being able to access and operate dams during emergencies. Failure did not occur in every case study examined; however, primary access was denied and the operators were not able to operate as they were trained to do. Dam owners should consider if these unanticipated scenarios occur can occur at their projects.

Noppikoski Dam (*Failed*) – Ore River, Sweden, 1985

The September 1985 flood was caused by extreme rainfall over the provinces of Dalarna and Halsingland in Central Sweden. The heavy rainfall occurred during the beginning of September with the largest rainfall occurring the 6th of September, when about 2.8 inches of rain fell over the northeastern parts of Dalarna and a large part of Halsingland. On the 7th of September an additional 0.4 inches of rain occurred. Large floods resulted, mainly in the Ore and the Voxnan rivers. The resulting flooding was the largest observed for the past 100 years.

On September 7, 1985, Noppikoski Dam on the Ore River in Sweden failed by overtopping, and the subsequent erosion reached the river bed within minutes. The volume of the reservoir was approximately 811 acre-ft and the dam height was 54 feet. The reservoir was emptied within 45 minutes after overtopping began. During the failure, the total outflow was about 21, 200 ft^3/s. Neither the discharge nor the stage hydrograph were measured downstream of the dam prior to the failure. Fortunately, there was no loss of life. Several bridges and the forest downstream were severely damaged.

The spillway had two bays with a discharge capacity of 4940 ft^3/s. Each bay used four iron stop logs that were raised with a conventional hoist, with a mobile motor and rack placed on a trolley. The stop logs were be removed if the water level reached a predetermined elevation. The hydropower dam was operated remotely by operators located at Furudal, 31 miles downstream of the dam. Project staff regularly conducted site visits a few days a week, or when needed. There were reservoir level sensors at the dam that are designed to warn the operators via radio and telephone if the reservoir levels exceeded maximum levels.

Failure Mode Event Tree:

- Excessive rain during the week of September 2nd
  - Friday, September 6th, evening operators attempt to visit the project; ***primary access to the project is denied*** because primary access roads are damaged by flooding. Alternate routes are approximately *25 miles* longer
    - 11:00 p.m. One operator arrives and reported that a stop log is jammed and the hoist equipment is not working
      - 11:00 to 11:45 p.m. The upstream dam Vassinkoski increased spillway discharge to 3350 ft^3/s to avoid potential failure. Crane company informs that they cannot find an operator this late on Friday evening
        - 12:00 a.m. – 3 a.m. Other engineers and staff bring tools to remove stop log ***but cannot access the project*** due to flood damage to roadway until about 3 a.m.
          - 3:30 a.m. Phone communication is lost from Noppikoski dam
            - 4:25 a.m. Crane arrives but is ***unable to access*** project because of a washed out road a few hundred meters from the dam
              - 5:25 a.m. Water begins to overtop and erode downstream embankment
                - 6:10 a.m. 811 acre-ft is released through the breached embankment

Breach of Noppikoski Dam on September 7, 1985

<u>Vassinkoski Dam (*Did Not Fail)* – Ore River, Sweden, Finland, 1985</u>

The Vassinkoski Dam is located upstream of the Noppikoski Dam and also experienced access difficulties during the 1985 flooding event. ***<u>Project staff were unable to access the project</u>***, because of flooding of access roads so a helicopter was requested but delayed. Telephone lines were destroyed however radio communications were still functional. Spillway gates were already opened; but due to the uncertainty of the spillway capacity during this event, project staff wanted to open the old diversion as well. Project staff eventually accessed the project via heavy tractor and opened the old diversion structure, and ultimately saved the dam.

<u>Euclides des Cunha Dam (*Failed)* – Brazil, 1977</u>

In 1977, a flood occurred that exceeded the design capacity of the Euclides des Cunha Dam. The spillway gates were not opened in time due to the operators' misinterpretation of the flood severity. When the decision was made to open the gates, opening of the spillway was not possible because ***<u>project staff were unable to access the dam due to access bridge being washed out</u>***. Ultimately, the dam failed along with another dam downstream. Fortunately there was no loss of life.

Gibson Dam (*Did Not Fail*) – Sun River, Montana, USA, 1964

Gibson Dam is a 199 foot high concrete thick arch dam with a crest length of 960 feet. The dam is located on the north Fork of the Sun River in central Montana. The spillway is a drop-inlet, discharging into a shaft and 29.5 foot diameter tunnel in the left abutment, controlled by six 34 by 12 foot radial gates. The only access to the dam is on a road along the North Fork of the Sun River, downstream of the dam.

In June of 1964, reservoir inflows reached extreme levels due to a combination of sustained up slope winds and unusually heavy moisture from the Gulf of Mexico. These conditions caused a rainstorm over a river reach 100 miles long on the eastern slope of the continental divide and produced 30 hour rainfall amounts from 8 to 16 inches. The shallow soils along the Rocky Mountains and foothills area were already saturated with spring snowmelt and there was very little capacity for retaining the flows. By 2 p.m. on Monday June 8th, overtopping of the dam began as inflows reached an estimated maximum of 60,000 ft^3/s and remained at this rate for 3 hours. A high water mark inside the spillway control house indicated the dam was overtopped by 3.23 feet. By 8 a.m. Tuesday, inflows had dropped to 30,000 ft^3/s and by 10 a.m. water stopped flowing over the parapet. The overtopping event lasted 20 hours.

A combination of the dam outflows and the additional heavy flow entering the river from Beaver Creek just downstream of the dam destroyed an access road bridge, a large storage building, and much of the access road downstream of the dam. Operating personnel were unable to get to the dam during the event because of ***loss of the access road*** early in the flood. This dam did not fail and experienced very little structural damage during the overtopping event. On May 28th, the day before water started over the spillway crest, the operators had left the river outlet discharging 1,800 ft^3/s, spillway gates No.2 and 5 fully open, No.3 and 4 completely closed, No.1 open 9 feet, and No.6 open 11 feet. With this gate configuration, outflow could reach 32,200 ft^3/s at a water surface elevation of 4729 feet. This would have passed the greatest previous flow of record, the flood of June 1916, without overtopping the dam. Later analysis indicated that the dam would have been overtopped by the 1964 flood even if all gates were fully opened as early as June 1st.

Post-incident Reporting for UK Dams

Beginning in January 2007, the post-incident reporting system in the UK was developed from historical data and to provide lessons learned from recent incidents. The purpose of these annual reports to the dam safety industry is to provide information on the nature of the lessons learned over the last year and trends in the number and type of incidents that have occurred.

2007 Annual Report

Incident 310

"A series of weirs, already in poor condition, were damaged during a flood event. One weir in particular, about 1.5m high and impounding about 12,000m^3, came close to breaching due to erosion around an abutment. It was not possible to access the sluice gate to lower the water level until the flood subsided."

Incident 321

"The reservoir was discontinued under the Reservoirs Act 1975, but not provided with adequate spillway capacity. Following heavy rainfall, the dam embankment was almost overtopped and evacuation of downstream houses was considered. An inspecting engineer was called to the reservoir, but he initially failed to reach the reservoir due to highway flooding."

Example of Initiatives Taken to Emphasize the Importance of Project Access

The experience of Hydro Quebec during the flood on the Saguenay River during July 1996 brought to light an array of operational problems that can occur when the largest flood of record must be passed. The Saguenay flood surpassed the 1000-year exceedance value and, when the actual 1996 flood flows were included in the peak-flow data base, estimates of the 10,000-year flood were tripled. Hydro Quebec found that many of their problems with gate operation were the result of inadequate maintenance.

Among other problems encountered with gate operation, one of the problems encountered involved:

Access to the gates was cut off and in several cases key operational people were not available or could not get to the dam site.

As a result, the Canadian Dam Safety Association recommended legislation to require access to gate structures ***at all times***.

CREDIBLE RISK REDUCTION MEASURES FOR DAM ACCESS

Accepting the fact that there is always risk involved with water retaining structures, it is important that the dam safety community consider the full range of risk reduction measures available, including both structural and non-structural risk reduction measures. Credible risk reduction measures include assuring the emergency readiness of key dam safety personnel, and any associated emergency improvements for operating the project and notifying Emergency Management Agencies (EMAs) responsible for evacuating people who may be affected by dam failure.

INTEGRATED SYSTEM VS. INDIVIDUAL COMPONENT APPROACH

This following paragraphs provide examples of when to evaluate emergency project access, specifically during the potential failure mode analysis, emergency action planning and review of the ODSP. The need to consider dam safety risk reduction measures as an integrated system is discussed.

Potential Failure Mode Analysis and Project Access

A Potential Failure Mode Analysis (PFMA) is an informal examination of "potential" failure modes for an existing dam or other project works by a team of people who are qualified either by experience or education to evaluate a particular structure. During the PFMA, detailed discussion is held regarding the possibilities for failure, loading by loading condition (static reservoir, hydrologic, seismic, ice, debris impact and any other loading relevant to the site) for each component of the project (main dam, spillway, gates, dikes, outlet works, power plant, etc.). Also, the total system operation aspects (communication and response [i.e., personnel, remote telemetry], facility access, weather conditions, equipment) with respect to the possibility of their contribution to development of a potential failure mode/failure scenario should be discussed.

Many dams were constructed without the benefit of instrumentation and thus visual observation provides the first line of defense to evaluate integrity, movement and loads. Visual observation at regular intervals by trained personnel will often detect unusual conditions, such as increased seepage, cloudy seepage, or movements and is the dam owner's primary defense against serious problems. Inspections/observations of remote projects which may not be accessible in winter conditions and may be covered by snow and ice must be specially addressed during the PFMA. The criticality of a particular potential failure mode will help determine the need for winter inspections/observations.

Emergency Action Planning and Project Access

Loss of life resulting from dam failure is influenced by many factors, one of which is the amount of warning that is provided to the population at risk. The more accessible a dam is, the more inspection and oversight it will likely receive, resulting in timely detection and verification of a dam safety problem and possible prevention of failure or increased warning time. The earlier problems are detected, the more warning time is available, providing more time to coordinate between project staff and emergency management agencies (EMAs), ultimately increasing warning time to the population at risk. For any dam where visual detection and verification of a problem are key steps in risk reduction, access is critical.

Part 12, Subpart C of the Federal Energy Regulatory Commission (FERC) regulations provides general requirements for emergency action plans (EAPs) at hydropower projects under the Commission's jurisdiction. The EAP must be: 1) developed in consultation and cooperation with appropriate Federal, State, and local agencies responsible for public health; and 2) designed to allow sufficient warning to upstream and downstream inhabitants, property owners, and operators of water-related facilities, recreational users, and others in the vicinity who might be affected by a dam safety emergency.

EAPs at FERC-regulated hydropower projects consist of six basic elements, one of which is Preparedness. In the Preparedness section of the EAP, one of the foci is describing primary and alternate access routes to the project. The description of access should focus on primary and secondary routes and means for reaching the site under various conditions (e.g., foot, boat, helicopter, snowmobile, etc.). Detail of the expected response (travel) time to travel these routes should be included for project staff and EMA response. Special attention should be given to access if the main access road crosses the downstream channel and could be affected by flood waters.

EMAs, first responders, or emergency supply contactors should have access to primary and alternate access information and be able to utilize this information during emergencies. Regularly performed EAP exercises should include scenarios where this information is utilized and discussed.

For projects that are operated remotely or visited only occasionally by a roving operator, and video surveillance or other instrumentation is not used, visual detection and verification of a problem depends on the ability to access the project. Questions that should be asked when evaluating access are as follows:

- Will access to the dam be cutoff due to flooding, rockfall, traffic, earthquake damage, etc.?
- Are all access routes to the dam from downstream?
- Will project staff drive upstream into a flood wave in response to an alarm while trying to get to the project?
- Are expected travel times a realistic representation of the time it would take during an actual emergency?

In addition to maintaining access to the dam, a prudent dam safety practice is to enhance the detection component (headwater and tailwater alarms) so it is capable of confirming a dam failure without requiring on-site investigation. Remotely monitored video cameras could be installed at the dams for immediate visual detection and verification of an emergency situation.

Emergency Action Planning and Project Access at United Kingdom Dams

The Department for Environment Food and Rural Affairs (Defra) is the UK government department responsible for policy and regulations on the environment, food and rural affairs. Defra provides guidance for developing off-site (used by emergency responders) and on-site (used by reservoir owners or those responsible for the operation of a reservoir) EAPs.

For off-site EAPs (as of May 2009), the following is provided to guide emergency responders with developing their EAPs relative to project access:

Overview map of location and immediate area showing:

- access routes, rendezvous points, control points for road blocks/closures and diversion routes and evacuation routes.
- *Alternative routes to dam highlighting how normal access routes might be affected by flooding or fallen trees;*
- weight/width/height restrictions on site and adjacent roads, vehicle size constraints;
- nearest locations suitable for helicopter landing;
- access around dam site and to structures, including key parts such as the abutments and all structures along the dam crest and downstream face.

For on-site EAPs (as of August 2009), Defra provides the following guidance for developing EAPs relative to project access to be used by dam owners and operators:

The on-site plan should provide enough detail for someone unfamiliar with the reservoir (for example an Inspecting Engineer, contractor's or undertaker's staff) to make their way safely from the nearest road to the reservoir, without any help, in the middle of the night. This should include alternative routes to dam and other features that may be necessary in an Emergency:

- how normal access routes might be affected by flooding;
- alternative access routes if serious flooding in the valley downstream of the dam blocks the main access;
- weight/width/height restrictions on site and adjacent roads, vehicle size constraints;
- nearest locations suitable for helicopter landing.

Access around dam site and access to structures, specifically:

- access to key parts of the dams such as the abutments, all structures, along the dam crest and downstream face
- any access routes which maybe blocked for any other reason, for example flooding, fallen trees etc.

Owner's Dam Safety Program and Project Access (Organizational Issues)

On a recent FERC dam safety inspection, it was learned that a State had experienced budget cuts, resulting in the roads no longer getting snow plowed. The operations staff informed management of the issue, hoping that the owner could request the State to continue to clear the roads or provide personnel and equipment to do it themselves. This issue was not addressed in a timely manner, and as a result the operations staff had to use equipment from a nearby city in response to an alarm at the dam. In another instance, operations staff had to hike to the dam because the roadway could not be used. Access to projects can be affected by an inadequate owner's dam safety program (ODSP) if the departments within an organization do not communicate when changes in operation or responsibilities occur. Project access should be evaluated during regular inspections regarding the total system aspects of personnel, ODSP, and emergency or operational facility access.

CONCLUSION

If personnel must be dispatched to dam to operate it or to determine the extent of an emergency, they have to be able to get there. Large flood events are typically accompanied by severe weather that may make roads impassible and helicopter travel impossible. Questions that should be evaluated include:

- Will access to the dam be cutoff due to flooding, rockfall, traffic, earthquake damage, etc.?
- Are all access routes to the dam from downstream?
- Will project staff drive upstream into a flood wave in response to an alarm while trying to get to the project?
- Are expected travel times a realistic representation of the time it would take during an actual emergency?

In summary, the following non-structural risk reduction measures relative to emergency access to projects were discussed in this paper:

- Project staff should be familiar with the location of project facilities including access routes from primary and alternate roads
- Dams are integrated systems and not individual components; regular review of total system operation aspects relative to facility access and potential failure mode risk reduction measures is essential
- Project staff responsible for inspection and observation should be trained to understand what standard operating procedures are in place during inaccessible times (i.e. winter, high flows, earthquakes, other contingencies, etc.)
- If operation of the project depends on access to the site, project staff needs to be able to get to the project. Stationing of personnel at the site before loss of access may be necessary
- The EAP should clearly define what alternate routes are available to the project
- During EAP exercises, the scenario being tested should include: Using alternate access routes (including extra travel times, need for special equipment, etc.), and questioning whether the expected travel times are realistic;
- If a project is remotely operated, a prudent dam safety practice would be to enhance the detection component (headwater and tailwater alarms) so project staff are capable of confirming a dam failure without requiring on-site investigation. Remotely monitored video cameras could be installed at the dams for immediate visual detection and verification of an emergency situation.

It is important that the dam safety community consider the full range of risk reduction measures available. Project access should be evaluated on a regular basis and be well understood by project staff.

As said by Mr. Russel L. Ackott, a pioneer for systems thinking, *"To manage a system effectively, you might focus on the interactions of the parts rather than their behavior taken separately."*

Potential failure modes, owner's dam safety programs, and emergency action planning and regular inspection are all critical elements to a good dam safety performance monitoring program. This paper illustrates how emergency access is a key emergency preparedness component and can be evaluated during review of these critical elements that are part of the overall system of dam safety.

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