Instrumentation and Dam Monitoring

Technology encourages increasing use.

By Barry Myers and Jay N. Stateler

The importance of monitoring programs for dam safety is widely accepted. There are many historical cases of dam failures where early warning signs of failure might have been detected if a good dam safety-monitoring program had been in place. The monitoring program provides the information that is needed to develop a better understanding of the on-going performance of the dam. Knowing that the dam is performing as expected is reassuring to dam owners, and the ability to detect a change in this performance is critical because the dam owner is directly responsible for the consequences of a dam failure. Therefore, a good dam safety monitoring program should be a key part of every dam owner's risk management program.

The use of instrumentation as part of dam safety programs is growing as the technology of instrumentation and ease of use improves. Instrumentation can be used to implement a monitoring program that provides more comprehensive and timelier information regarding the on-going performance of the dam. With this information dam owners can improve their ability to responsibly operate and maintain the dams in a safe manner.

Instrumentation as defined here is a device that is installed to measure a particular parameter of interest. These parameters might include seepage flows, seepage water clarity, piezometric levels, water levels, deformations or movements, pressures, loading conditions, temperature variations, or the accelerations experienced by the dam during an earthquake, for example. The measurement from the instrument may be electronic or made by using a mechanical device. Instrumentation is typically provided at dams to deal with informational needs that are most efficiently and effectively addressed by installing and reading instruments. Instrumentation is used in conjunction with other available information gathering approaches to comprise the complete monitoring program for a dam. Some of these other approaches are:

- Visual examination/inspection
- Video surveillance
- Photographs, including perhaps a series of photos from a particular vantage point
- Audio recordings
- Water quality sampling programs
- Limited duration data gathering programs, such as geotechnical and/or materials testing of in-situ or laboratory samples, self-potential testing, thermal monitoring, resistivity surveys, seismic reflection/refraction studies, ground penetrating radar, etc.
- Geologic exploration programs, involving drill holes, test pits, etc.
- Dam/reservoir operations data and reports

The benefits of instrumented monitoring include the following:

- Instrumented monitoring produces quantitative data. The accuracy and sensitivity of the monitoring is defined as the instrumentation program is designed.
- Instrumented monitoring can produce data and information on foundation conditions and within the interior of structures. Except for exploratory drill holes, other methods are limited to what can be observed at the ground surface and at the exterior surfaces of a structure.
- Instrumented monitoring can provide long term, consistent records of data, allowing for detection of subtle trends in the dams' performance under different loading conditions that may develop slowly over time. Other methods of observation tend to provide short-term, discrete records of information.
- The collection of instrumentation data can be automated, which allows for monitoring on a more frequent (near real time) basis. Automated monitoring systems can be used to initiate alarms for notifying dam monitoring personnel of sudden changes in the instrument data values due to normal or extreme loading conditions such as earthquakes and flooding.

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Dam Life Phases

During its life, a dam can be considered to have several different phases. Monitoring needs vary depending on which phase the dam is in. Informational needs that can be effectively addressed by instrumented monitoring can arise at a number of different times in the life of a dam.

Design Phase. Field investigation work is typically the key information-gathering method used during the design phase, given the one-time need for characterizing the geology and materials at and around the dam site. Instrumentation can be used as part of this investigation work to establish baseline conditions for items such as groundwater levels and downstream spring flow rates relative to design, construction, or potential legal issues. Some of the instrumentation used for characterization during the design phase may also be used to monitor and evaluate changes in baseline conditions during the construction and first reservoir filling phases. Instrumentation that is shown to provide good information regarding the key performance parameters for the dam would be incorporated into the long-term monitoring phase as well.

Construction Phase. Issues that come up during the construction of a new dam, or modification of an existing dam, where instrumentation has a role, include:

- Confirmation of design assumptions
- Changes in groundwater and stability conditions both on site and at adjacent sites
- Worker safety
- Construction quality control

For all of these issues the ability to continuously monitor the parameters of interest using instrumentation can be advantageous in detecting and correcting problems that arise during construction. This information can become especially important if design modifications are required as a result of unexpected performance.

First Reservoir Filling Phase. This phase is probably the time in the life of the dam when performance monitoring activities (visual and instrumented monitoring) are most critical. As the reservoir is filled, the seepage resistance of the dam, foundation, abutments, and reservoir rim are being tested for the first time. Also, the reservoir load first tests the structural suitability of the dam. During this time of initial testing of the dam, instrumentation typically is used for:

- Providing an early indication of unusual or unexpected performance.
- Providing confirmation of satisfactory performance.
- Providing information and data so that actual performance of the dam (under reservoir load) is better understood.

Long-Term Phase (Normal Operations). Instrumented monitoring in this phase has a similar role to the first reservoir filling phase. At this point in the life of the dam, a significant body of information has most likely been developed about the dam and dam site. The information and data collected during previous phases of the dam can be used to identify the dam safety issues of current concern. These issues may be significantly different than those existing prior to initial reservoir filling. Therefore, a new assessment of the areas of concern and the information that should be provided by the instrumentation program may be appropriate.

Dealing with Unexpected Performance. Though we hope our dams never go through this phase, the reality is that some dams will. The fundamental instrumented monitoring roles associated with this phase are: 1) assisting in defining the problem (where appropriate), and 2) providing a means of confirming that the problem has been successfully addressed by the chosen remedial actions.

Other Monitoring Needs

In addition to providing data and information that can be used to assess performance of the dam, the data provided by instrumentation can fulfill other needs. These other needs are secondary with respect to the safe performance of the dam, however, they may also be important.

Legal. Quantitative documentation of some parameter may be needed for legal reasons. For example, documentation of groundwater levels in areas adjacent to a reservoir may be needed for legal reasons to effectively deal with claims of changes in groundwater levels caused by filling of the reservoir of a new dam.

Research. Instrumentation may be selected not to directly benefit the dam in question, but to expand general knowledge to benefit future dam design efforts.

Changing Monitoring Needs

Because the monitoring needs for a particular dam change over time, it is important to reevaluate the monitoring program regularly. This reevaluation is needed to determine if the correct information is being provided to effectively monitor the on-going performance of the dam. Monitoring efforts that are focused on parameters that are no longer important can distract from the parameters that have become critical regarding the future safe performance of the dam. This can produce a false sense of security. To assist with the task of reevaluating the monitoring needs during the life of the dam, a process called potential failure modes analysis (PFMA) is currently being utilized by dam safety practitioners.

The PFMA process represents a recently developed approach that is gaining more widespread use. The PFMA process involves:

1. Identifying the potential failure modes for the dam that warrant attention at the present time (based on all currently available information and data).

2. Defining an appropriate monitoring effort relative to each identified potential failure mode (appropriately balancing the monitoring costs with the risks and consequences associated with each failure mode).

3. Defining expected and unexpected performance associated with each monitoring effort, to provide a framework for the people charged with carrying out the routine dam safety monitoring to identify developing conditions of concern.

The monitoring programs developed using the PFMA process generally include a program of routinely performed, failure mode-based visual inspections carried out by operating personnel. The programs also typically include instrumented monitoring with respect to some key failure mode-based monitoring parameters, and the use of previously listed other information collection approaches. The PFMA process applies not only to failure modes that might occur under normal operating conditions (static loading conditions), but also to failure modes that might occur under the extreme loading conditions of floods and earthquakes.

Instrumented monitoring that is included to detect developing potential failure modes effectively addresses the issues of 1) providing an early detection of unusual/unexpected performance, and 2) providing confirmation of satisfactory performance. It may not directly address the issue of providing information to better understand the actual performance of a dam (as compared to the changes in performance with time).

At the point in the life of a dam

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where initial (first reservoir filling) performance concerns have been satisfied and the dam is in a long-term, normal operations mode, significant performance information about the dam is typically available (i.e., visual monitoring information as well as instrumentation data). For most dams it is generally not appropriate to perform costly and potentially risky endeavors, such as drilling holes in the core of an embankment dam to provide additional instruments, only to add to the understanding of the actual performance of the dam. However, there is a place for continuing monitoring activities that are not failure mode-based if they provide information that is valuable in tracking the on-going performance of the dam without adding risk to the dam or high costs to the monitoring program.

Virtually all of the life of a dam is spent in the long-term, normal operations phase. Therefore, it is important to have a well-thought out and rational approach for identifying the changing monitoring needs for the dam, so that efficient and effective monitoring programs are used.

Summary

An effective dam safety monitoring program is essential for dam owners to manage the risks associated with the operations and maintenance of a dam. The use of instrumentation can improve the dam owner's ability to monitor the on-going safe performance of the dam by providing more comprehensive and timelier information. Attributes of instrumented monitoring that can make it the best choice relative to a particular situation include: 1) quantitative data is obtained for use by dam safety personnel in evaluating the ongoing performance of the dam, 2) data regarding the foundation and interior of structures can be obtained, 3) the instrumented data collection can be long-term in nature so that a steady stream of repeatable data can be produced for detection of subtle trends that may develop slowly over time, and 4) the collection of instrumentation data can be automated allowing for more frequent (near real time) monitoring of the dams performance under both normal and extreme loading conditions.

Monitoring needs vary over the different phases that occur during the life of a dam. These phases typically include design, construction, first reservoir filling, long-term (normal operations), and dealing with unexpected performance. Instrumented monitoring can be an effective tool for obtaining the information needed during these different phases. In addition to monitoring the performance of the dam, instrumentation data can also be valuable for legal or research considerations.

Instrumented monitoring efforts during the long-term normal operations phase must be tailored to actual, current monitoring needs, as opposed to a continuation of reading of whatever instruments have been installed over time at the dam. Evaluation of the changing monitoring needs for a dam can be accomplished using the PFMA process. The results of the PFMA process provide an effective means of focusing the dam safety monitoring efforts during the long-term normal operations phase so that the monitoring program is both effective and efficient. The PFMA process involves: 1) identifying the potential failure modes for the dam that warrant attention at the present time (based on all currently available information and data), 2) defining an appropriate monitoring effort relative to each identified potential failure mode, and 3) defining expected and unexpected performance associated with each aspect of the monitoring program.

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Inspect Your Vehicle Lifts

Here is an important message for local government fleet maintenance facilities: Remember to inspect your lifts. Maintaining a safe and efficient repair shop is everyone's responsibility. Technicians should check their lifts every day, and professional lift inspections should be scheduled annually. Regular inspections help ensure that all the lifts in the shop are operating properly. In addition to daily operator inspections, the Automotive Lift Institute (ALI) recommends that all vehicle lifts be inspected by a qualified lift inspector at least annually, "to ensure reliability and the continued safe operation of the lift."

The owner's manual will provide inspection instructions for a specific lift. General guidelines are also available from the Lifting It Right safety manual published by ALI, and ANSI/ALI ALOIM:2008, the industry standard that outlines safety requirements for lift operation, inspection, and maintenance. Both publications are available from ALI members and their distributors, as well as from ALI's website at www.autolift.org.

At a minimum, technicians should check the following daily:

1. Lift controls are working properly.
2. All locks and restraints are working correctly.
3. There is no deformation or excessive wear of any lift components, including posts, arms, hoses, or wiring.
4. There is no damage or excessive wear on any of the lift contact points, including adapters.
5. There are no hydraulic leaks.
6. There are no cracks or loose concrete around floor, if applicable.

Rotary Lift has produced a new Inspect to Protect video highlighting the importance of vehicle lift inspections. Check it out on Rotary's YouTube channel, www.youtube.com/RotaryLiftMedia.