United States Society on Dams

Development of a Dam Safety Instrumentation Program

April 2013

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Prepared by the USSD Committee on Monitoring of Dams and Their Foundations

U.S. Society on Dams

Vision

To be the nation's leading organization of professionals dedicated to advancing the role of dams for the benefit of society.

Mission — USSD is dedicated to:

- Advancing the knowledge of dam engineering, construction, planning, operation, performance, rehabilitation, decommissioning, maintenance, security and safety;
- Fostering dam technology for socially, environmentally and financially sustainable water resources systems;
- Providing public awareness of the role of dams in the management of the nation's water resources;
- Enhancing practices to meet current and future challenges on dams; and
- Representing the United States as an active member of the International Commission on Large Dams (ICOLD).

Printed in the United States of America

ISBN 978-1-884575-63-3

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FOREWORD

The importance of monitoring programs for dam safety is widely accepted. A well designed and executed instrumentation monitoring program can provide information that is needed for a solid understanding of the ongoing performance of a dam and may help detect early warning signs of trouble. Monitoring programs, including instrumentation and visual inspection, provide dam owners with the knowledge that a dam is performing as expected and the ability to detect a change in performance. This knowledge and ability 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.

This paper is part of a series of White Papers by the USSD Committee on Monitoring of Dams and Their Foundations to address important topics with respect to the development and successful implementation of dam safety monitoring programs:

- Why Include Instrumentation in Dam Monitoring Programs?
- Routine Instrumented and Visual Monitoring of Dams Based on Potential Failure Modes Analysis
- Development of a Dam Safety Instrumentation Program
- Operation and Maintenance of an Instrumentation Program
- Instrumentation Data Collection, Management and Analysis

While each of the above White Papers addresses its topic in a "stand-alone" manner, there are interrelationships between these papers. Readers of this paper may find it beneficial to refer to one or more of the other White Papers for a broader understanding and perspective with respect to dam safety monitoring programs.

This series of White Papers primarily addresses the programmatic aspects of instrumentation for dam safety monitoring rather than technological advances in instruments. These papers should provide dam owners, large and small, with basic information to evaluate or implement an adequate dam safety monitoring program. These programs become more and more critical as our nation's dams (and other infrastructure) reach and extend beyond their design lives.

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The work of these individuals, and that of other Committee members who provided input regarding this paper, is acknowledged and appreciated.

TABLE OF CONTENTS

1.0 INTRODUCTION

The use of instrumentation to monitor the performance of dams is widely accepted as a prudent component of a successful dam safety program to manage and minimize the risks to the public posed by dams. Instrumentation observations are used to supplement and complement visual inspections to verify the integrity of the dam and appurtenant features, assuring protection of life and property.

Instrumentation provides data for monitoring the safe performance during the various phases of a dam's life including design; construction; first filling of the reservoir; evaluation of long-term, in-service performance (normal operation); and to manage or predict unsatisfactory performance. Installation of instrumentation typically occurs 1) during construction to monitor short and long term behavior and verify design assumptions; and 2) during the life of the dam to address new or changing conditions such as seepage.

General guidance for the development or modification of an instrumentation program can be found in many references, such as the Federal Emergency Management Agency's *Federal Guidelines for Dam Safety*, Section III, Part D, "Management of Technical Activities for Operation and Maintenance," as well as the Federal Energy Regulatory Commission's *Engineering Guidelines for the Evaluation of Hydropower Projects*, Chapter 9, "Instrumentation and Monitoring" and Chapter 14, "Dam Safety Performance Monitoring Program." Additional guidance provided by the Corps of Engineers, Bureau of Reclamation, American Society of Civil Engineers, and various manufacturers and suppliers can be found in the references listed at the end of this document.

The function, purpose, and type of instruments may vary widely, depending on the specific application, from a simple v-notch weir to a complex network of automated vibrating wire piezometers. Data acquisition methods can also vary widely from manual readings to automated data acquisition with periodic data recording capabilities. If in-house expertise is not available, engineering consultants, instrument manufacturers, or suppliers can be consulted to help identify an instrumentation program appropriate to the project. Dam owners with multiple dams should note that an instrumentation monitoring program established at one dam may not be appropriate at another dam regardless of the extent of similarities. Therefore, it is imperative that each project be evaluated independently to assess the objectives of the instrumentation program. The evaluation should be part of a structured process that identifies plausible failure modes unique to a dam and develops appropriate responses, including instrumentation requirements.

Dam owners should carefully evaluate the need for instrumentation, periodically review the need, and modify the program accordingly when specific issues of performance arise. Among several considerations in developing an instrumentation program, the following items will be discussed in this paper:

- Standard procedures of a dam safety instrumentation program
- Assessment of instrumentation requirements

- Experience and qualifications of personnel
- Budgets for activities of the program
- Implementation of program — procurement and installation

2.0 STANDARD PROCEDURES

Regardless of whether or not the project is a new dam requiring instrumentation or is an existing structure where the need for monitoring has become prudent, establishing and implementing certain procedures can facilitate meeting the instrumentation program's goals and objectives. These should include standard procedures for responsibilities related to installation of instruments, data collection and evaluation, and maintenance of the system. All are considered necessary for the instrumentation program to be effective.

2.1 Responsibilities

Most successful organizations, in any endeavor, clearly define the roles of their personnel; certainly this is an important procedure in the management of dam safety instrumentation programs. Personnel involved in an instrumentation monitoring program would preferably include a technical supervisor, engineers, and technicians. However, regardless of the titles used, and depending on the size and how the group or entity is organized, the most important concept is that responsibilities for acquisition of data, maintenance of instrumentation, interpretation and reporting of data should be clearly defined (this may be filled by one person or a full crew of dedicated personnel). Essential to this is to identify those responsible for accurate, clear and prompt communication to the dam owner of any conditions identified by the instrumentation program that may be adverse to the safety of the dam.

2.2 Monitoring Planning

Planning of instrumentation, whether for an existing dam, or during the design phase for a new dam, includes several essential considerations. Considerations include selecting the parameters for monitoring; defining the purpose of the instrument; predicting the life cycle of the instrument and its replacement challenges; predicting the influences that drive fluctuations; predicting the range of measurements expected; and establishing thresholds for safe performance. After logically evaluating these considerations, an appropriate instrumentation system then may be selected. The Potential Failure Mode Analysis procedure is a valuable tool for planning and selecting the parameters for monitoring. It is discussed in detail in the USSD White Paper, *Routine Instrumented and Visual Monitoring of Dams Based on Potential Failure Modes Analysis*.

2.3 Installation of Instruments

Installation of some types of instrumentation systems or individual instruments may be accomplished in-house while other systems or instruments may require specialized expertise. However, consultation and coordination with engineering consultants as well as instrument manufacturers or suppliers is recommended as they can provide assistance

with instrument selection, installation, calibration, maintenance, and future troubleshooting. If possible, manufacturers should provide those responsible for data monitoring with the necessary training related to installation, operation and maintenance of the instruments to ensure that they fulfill their purpose.

As an owner, documentation of the installation is important and should be formulated to include the procedures for installation as well as the steps necessary for operation (i.e. troubleshooting concerns, connection to data loggers, etc). Documentation should include the technical requirements of the instruments, calibration requirements, installation details, and servicing requirements and methods.

2.4 Data Collection and Evaluation

Consideration of methods to collect the data must be evaluated. Data collection may be via either an automated data collection system or manually (using a readout device or conventional pen and note paper to record readings). Depending upon the type of system designed and installed, procedures should be developed to include how instruments will be read (frequency of readings, time of day, conversions to other units, etc.) and how data reports can be generated when needed. Decisions regarding data storage (physical and electronic) will vary from project to project. If a central storage system is used, procedures to access the reports or manipulate them should be documented.

Evaluation of data collected is vital for achieving the goals of effectively monitoring the performance of the dam structures. It is of the utmost importance that data be regularly and promptly evaluated as it is collected; standard turn-around times from collection to evaluation should be established, as well as procedures to address how abnormal readings are handled. It is recommended that an annual monitoring report be prepared with an evaluation of the instrumentation data for submittal to the dam owner. The report should include a comparison of recent behavior to historical trends and conclusions as to the performance of the dam with respect to the parameters measured.

2.5 Maintenance

Once the program is developed and implemented, the dam owner must consider long-term maintenance of the system. This includes documentation of the instruments and data logging equipment and how they are to be maintained. Such items as a maintenance schedule, maintenance logs, processes for each instrument and system component type, and other maintenance needs should be addressed on a site-specific basis. Manufacturers' Operation and Maintenance (O&M) manuals should be available for the life of the instrument. If possible, training on the general maintenance and trouble-shooting of the instruments should be provided at the time of installation.

3.0 ASSESSMENT OF INSTRUMENT REQUIREMENTS

A well-accepted industry principle is that no instrument should be installed if it is not intended to answer a specific question or monitor an identified potential failure mode of the dam or foundation. In other words, it is a valuable investment, both in time and money, to properly evaluate and define instrumentation needs in relation to a question about a dam's performance. If an existing instrument no longer provides useful data then retirement of the instrument should be considered.

Assuming that the specific question to be answered or potential failure mode is identified, sources of information to assist in the selection of the proper instrument include internal organization resources, other dam owners, instrument manufacturers, engineering consultants, and firms specializing in instrumentation design and installation. Guidance from technical manuals and documents may also be found from references listed at the end of this paper.

Dam owners should evaluate their instrumentation requirements using the Potential Failure Mode Analysis (PFMA) process. The PFMA process is used to identify potential failure modes at a specific project or project feature at the time of evaluation. These modes can help evaluate and select project features where instrumentation may or may not be needed for inclusion in the monitoring program. The PFMA evaluation must be thoughtful and thorough, and include input from the dam owner, operating personnel, independent engineering consultants, regulatory agencies, and designers familiar with the dam and foundation.

Construction of a V-notch weir to measure seepage at an embankment dam.

Among the decisions to be made are deciding what generic type of instrument is required and then what specific type. For example, to monitor seepage, the decision may be that a

weir will be required. Then a decision must be made on the specific type of weir (e.g., V-notch, rectangular, Parshall flume) and whether to use a visually read staff gauge or an electric water level transducer. There are then various level transducers available: float-type devices with a vibrating wire or magnetostrictive transducer or diaphragm pressure transducer, each with their own advantage and disadvantage. The type of instrument selected will be influenced by the time of installation - during original dam construction, before first reservoir filling, or with a full reservoir (possibly after many years of operation).

Another example is how to monitor pore water pressures in embankment cores or uplift pressures in foundations. Among the generic types of instruments, the choices range from: standpipe piezometers with a Casagrande tip, read manually with a water level meter, to electric or pneumatic piezometers lowered into a standpipe. Then, as an example, in terms of specific types of instruments for electric piezometers, there are vibrating wire piezometers or piezoresistive piezometers, each of them available in vented or unvented versions. Piezometers may have been installed during initial construction of the dam, or installed later in conjunction with drilling to obtain samples for material strength testing.

Standpipe piezometer at the downstream toe of an embankment dam.

Each type of instrument involves a different installation method, some being more disruptive than others for the material in which they are installed, especially for earth core materials of embankment dams. The installation method needs to be considered as an integral part of the instrument selection process. Additionally, for most instrument choices, another consideration is whether to use manual or automated reading, and in the case of automated reading, with or without telemetry to transfer the readings to a site office or a remote location.

These examples illustrate that the process of defining needs can indeed involve numerous options for the same instrumentation objectives. This is why detailed and careful planning is essential in order to achieve savings in the overall process while meeting technical objectives.

Minimum instrumentation recommendations can be found in the Federal Energy Regulatory Commission's publication, *Engineering Guidelines for the Evaluation of Hydropower Projects*, Chapter 9, Tables 9-4a and 9-4b; and typical instrumentation for common problems in Table 9-4c.

4.0 EXPERIENCE AND QUALIFICATIONS

A familiar adage among dam safety professionals states that one of the best instruments for monitoring is a human eye attached to an alert and conscientious human brain.

Successful development and management of an instrumentation program necessitates an awareness of experience and qualifications so that:

- Personnel with the required knowledge and experience may be assigned appropriate responsibilities
- Appropriate training may be instituted to develop expertise
- Assurance that correct evaluations of the performance and safety of dams are the products of the program.

The most important requirement is that all members of the team, whether comprised of two or twenty, are knowledgeable and interested in dam safety and performance, and appropriate training is provided as needed.

Although a technical degree is desirable for technicians, the most important educational requirement is dam safety training whether by internal or external sources. An interest in and aptitude for measurements, whether gathering data in the field, downloading information from electronic data collectors, or tabulating data for charts and graphs for evaluation, is of high importance for technicians. The ability to correlate field measurements to engineering parameters is essential for all individuals evaluating data. It is important that thresholds or action levels be provided to the technicians so they can take appropriate actions when a threshold level is exceeded. Training and instructions for appropriate actions must be provided as well.

Educational requirements for engineers may include a degree in civil engineering (with a focus on geotechnical or geological engineering). Civil engineering curricula provide studies in structural engineering, geotechnical engineering, surveying and engineering geology, all of which are relevant for data evaluation. However, very few engineering scholastic programs are specifically aimed at dams and their monitoring systems making on-the-job training essential. Seminars and workshops sponsored by such organizations as the United States Society on Dams, the Association of State Dam Safety Officials, the

American Society of Civil Engineers and the Federal Emergency Management Agency offer valuable dam safety instrumentation training.

Engineers who have experience designing dams are very desirable personnel for an instrumentation program; however, at a minimum, engineers involved in a project's instrumentation program should understand the basic fundamentals for the design of dams; knowledge of stability and seepage analyses; and knowledge of how parameters measured by instruments are used to evaluate performance of dams. Staff should have a basic understanding of how various instruments work and have experience designing, specifying, installing or maintaining instrumentation or be able to contact and interact with someone who can provide that expertise.

4.1 Project Specific Knowledge

While general knowledge of dam design, analyses, and parameters measured at dams is desired for personnel engaged in an instrumentation program, site specific knowledge is imperative. Interpretation of data to determine the performance of dams can vary significantly based on site location, condition and maintenance of instrumentation, geology, foundation conditions and treatment, seepage control features, construction and design details. Personnel who have consistently monitored projects over long periods of time have project-specific knowledge that makes them an extremely valuable resource for dam safety programs.

For example, where seepage may be measured at weirs downstream of dams, it is essential for the individual interpreting the measurements to know whether this is seepage from an internal drainage system of the dam, or from leakage that is bypassing cutoff features. Project specific knowledge of the reason for installation of the weir and the parameter measured is essential.

All involved in the program and monitoring should be aware of the plausible potential failure modes and correlations to the instrumentation at the project. For example, perhaps a dam has a postulated failure mode of leakage through an abutment with material that can be easily eroded; a significant increase of abutment leakage measured at a weir, or accumulation of material in the approach channel of the weir, could be an indicator of a potential problem. Even if formal reviews of possible failure modes for a project have not been performed, site-specific knowledge of the project design, geology, and historic performance and observations can help interpret the project's performance.

Project specific knowledge will allow those responsible for evaluating data to identify anomalous data and identify trends and atypical performance which contributes to quick and early identification of potential problems. Such knowledge will also enable the reviewer to quickly identify erroneous readings or measurements.

4.2 Instrument Specific Knowledge

Instrument specific knowledge, i.e. types of instruments, their purpose, and installation details are critical in the identification of potential problems and in the evaluation of the performance of dams.

For example, dam owners may install a variety of piezometers: standpipe; vibrating-wire; pneumatic; or hydraulic. If personnel involved in the instrumentation program understand the differences in response, accuracy, and weaknesses of these types of piezometers, more accurate interpretations of performance will be realized. Knowledge of the installation details of each type of piezometer will provide insight to the function of the instruments; e.g., open standpipe or observation wells which measure an overall water surface versus those piezometers which are screened at levels to measure pore water pressure in specific zones.

4.3 Basic Knowledge of Fundamentals for Design of Dams and Foundations

Those responsible for interpreting data from dam safety instrumentation must understand the basic principles of dam design to correctly determine the safety and performance of the project. For example, depending on the project components, the individual should be able to answer and understand the following questions:

- How is seepage water controlled by design features in both concrete and embankment dams and their foundations?
- How do foundation drains in concrete dams affect uplift pressures?
- What assumptions are used for stability for both concrete and embankment dams?
- How do soil properties affect performance of embankment dams and foundations?
- How do geological features of foundations affect the safety of dams?

Merely noting the fluctuations of data represented by charts in an instrumentation report does not constitute interpretation of safety or performance of dams. An accurate interpretation of the safety and performance of a dam is the goal of a well-managed instrumentation program. To do this, the responsible individuals must be able to relate the parameter being measured to how it is used in the design of a dam.

4.4 Understanding Measurements

To avoid misinterpreting data from measurements of dam safety instrumentation, knowledge of measurements and errors is very beneficial. Knowing that errors occur in measurements without corrupting the value of the data, while mistakes are bona fide reasons for rejection of data, gives the reviewers of data the perspective needed to identify the implications of anomalous data. For example, spikes in leakage readings may be caused by rainfall or snowmelt.

An understanding of statistics helps to distinguish errors from mistakes. Knowledge of the laws of probability, formula for standard deviation (standard error), definitions of

mean, average, median, and significant figures may be useful for personnel interpreting data.

5.0 BUDGET CONSIDERATIONS

Lawrence H. Roth, then Deputy Executive Director of the American Society of Civil Engineers, testified before committees of the U.S. House of Representatives on May 8, 2007: "Like all man-made structures, dams deteriorate. Deferred maintenance accelerates deterioration and causes dams to be more susceptible to failure. As with other critical infrastructure, a significant investment is essential to maintain benefits and assure safety."[1] A sufficiently funded monitoring program for instrumentation and visual inspections is vital for the maintenance and safe performance of dams.

To efficiently use those limited resources available to the dam owner, managers may be required to evaluate and justify their programs. However, depending on the size of the organization, managers at various levels may have limited backgrounds in Dam Safety in general and Instrumentation Monitoring Programs in particular. Also, instrumentation programs do not easily fit into usual economic evaluations such as cost to benefit ratios and productivity comparisons. These managers may find it difficult to judge if funding for the instrumentation program is inadequate, adequate, or excessive.

Given the economic and political pressures on most organizations, both public and private, to reduce operating and maintenance budgets, what are some reasonable bases on which to judge the adequacy of funding for instrumentation programs? Quite often, useful information for budget may come from:

- A dam safety risk assessment that identifies and prioritizes risks may be useful to justify budget decisions. A structured risk assessment, as discussed in the USSD publication, *White Paper on Dam Safety Risk Assessment*, provides a framework to communicate technical issues and engineering judgment to non-technical managers or owners
- Staff professionals who have experience in instrumentation programs
- Consultants with experience in instrumentation programs
- Attendance at professional meetings, training, workshops, such as those sponsored by the United States Society on Dams, Association of State Dam Safety Officials, the American Society of Civil Engineers, or others.
- Other dam owners who are willing to share staffing and budgeting information. However, this type of comparison should be done carefully. As dams are unique structures, and their monitoring needs variable, comparisons with other projects can be done, but with caution.

[1] *ASCE News*, Volume 32, Number 6, "Roth Testifies Before House Subcommittees, Conveys ASCE's Support for Levee and Dam Safety Programs", p. 8, June 2007.

5.1 Activities Requiring Funding

Those managing Dam Safety Instrumentation Monitoring Programs should be familiar with the various activities that require funding for instrumentation programs. Some of these activities include installation; data collection and evaluation; maintenance; and replacement.

Unforeseen Installation of Instrumentation: Managers of dam safety programs, particularly those with several dams, may find it prudent to provide money in their budget for installation of instrumentation, and an increase in staff time for physical monitoring or manual readings to address an unexpected concern that may arise. Also, it is prudent practice to increase the frequency of observations of new and existing instrumentation to fully evaluate an unexpected problem. It is not unusual for existing dams to develop problems that require additional or new monitoring. For example, leakage or seepage may be found where none has been previously; cracks or displacements may be noted that had not been identified during prior inspections; sinkholes may appear on embankment dams; as well as many other greater or lesser problems. The initial and consensus action of responsible personnel is almost always the same – monitoring and measurement of some parameter associated with the problem.

Training, Data Collection, Evaluation, and Maintenance: Sufficient budget to include regular dam safety training to keep up to date on instrumentation and monitoring technologies should be considered. This can include attendance of meetings of professional organizations, technical seminars or classes, and internal or external dam safety training. Probably there are few program activities where continuing training is as important to the quality of the product as the evaluation of dam safety data and its implications.

If consultants are being considered for evaluation of instrumentation data, sufficient budget should be allotted to allow for regular communication with the consultant. This should include more than an annual consultation for evaluation of data – data should be constantly evaluated.

With the continuing and increasing importance of automated data acquisition for data collection, adequate budget should be provided for software and hardware upgrades. Also, the software and computer hardware used for evaluation and reporting should be taken into account for program budgets.

If automated data acquisition is considered at a site to replace manually-read instrumentation or to automate reading of existing instrumentation already suitable for interfacing to automated data acquisition systems, the budgetary implications will need to be adequately planned. Implementing an automated data acquisition strategy may imply replacing or upgrading instruments, acquiring and installing the data acquisition system, training personnel on hardware and software and budgeting for future maintenance and upgrades. Long-term maintenance of data, whether in hard copy or electronic database, should be another consideration in budget allocation.

Maintenance of Instrumentation: To obtain accurate and reliable data, dam safety instrumentation requires on-going and timely maintenance. Even such simple instruments as a weir require occasional cleaning of the approach channel and weir blade or repairs to prevent leaks. More complex instruments may require instrument mechanics, electricians, computer technicians and information technology support as well as calibration by, and shipment to, original manufacturers. Instrumentation budgets should also be adequate for maintenance activities such as mowing, spraying, signage, and painting that preserve access to, and identification of, instruments.

Replacement of Instrumentation: For monitoring programs of any size, managers should include an allowance for periodic replacement of instrumentation. Instruments may be damaged by vandalism, lightning, grounds maintenance activities, construction, or mishandling. While care should be taken to discontinue any and all instruments that do not have a reason to exist, damaged instrumentation should be promptly identified and replaced, or repaired as deemed necessary.

6.0 IMPLEMENTATION OF PROGRAM — PROCUREMENT AND INSTALLATION

Once a program has been developed, several steps need to be taken to procure, install, and implement the system. Depending on the size of the instrumentation program and other considerations including procurement procedures and rules that may vary from one organization to another, the procurement method may vary from a simple phone call to an instrumentation manufacturer or a firm specialized in instrumentation design and installation to a formal bidding process.

6.1 Procurement Methods

If a bidding process is selected, specifications and drawings must be prepared that may include details on the required type of instrument, the installation locations, the qualifications of the installation personnel and their supervision, the method and frequency of reading, environmental concerns, and the payment method.

The procurement method to be chosen may depend on the number of required instruments, the anticipated difficulty of installation, and legal requirements governing the buyer. In most cases, and especially when installation is by far the most delicate step of the process, the decision on the procurement method should allow for evaluating the qualifications of the bidding firms and should not be based solely on a lower cost bidding approach. Depending on the team's familiarity and level of expertise with instrumentation, engineering consultants may be considered to assist in this process.

A Request for Proposal (RFP) method may be used where low cost is not the sole consideration and the buyer is not required to use competitive low cost bidding procedures. For installation services, long-term maintenance services for hardware and software, large projects, and corporate goals, the RFP method may be desirable. It allows bids to be evaluated for:

- technical expertise
- equipment and materials proposed
- personnel qualifications
- financial and business strength
- safety and environmental concerns; and
- price

Each factor should be weighted for evaluation of proposals. Often, this method results in a more favorable combination of quality and price, than procurement by low bid price alone.

6.2 Equipment Services

Instrument requirements and installation may not be the only two components of the procurement. Very often, an automatic data acquisition system is also required as well as the communications, such as radio, satellite, or cell phone modem to retrieve readings from the site and transmit to a site office or a regional office. Software for data management may also be part of the procurement, together with the initial software configuration to satisfy initial requirements for collecting and reporting instrument readings. Clauses for technical support and maintenance on hardware and software should also be included in the procurement package.

6.3 Contractual Arrangements

Contractual arrangements for procurement may vary from case to case, as discussed above. The main objective is to select qualified firms, both as supplier and as installer, in order to ensure that instruments will provide valuable and reliable readings over the life of the installation. Industry-standard warranties on instruments are generally of the order of 12 months. This is far less than the anticipated life of the installed instruments and records abound of instruments that are providing accurate data many years after installation, in many cases for decades. The objective is therefore to provide a contractual framework that will allow a proper job to be executed while maintaining a competitive environment.

6.4 Initial Check and Calibration

Once instruments are procured and received on site, they should be subjected to a functionality test in order to confirm that they are in good condition and that they have not been damaged by shipping. The functionality test will vary from one type of instrument to another. For electrical instruments, it may simply consist in connecting the instrument to the readout unit and confirm that the initial reading is substantially identical to factory initial reading on the calibration certificate of the instrument. Depending on the type of instrument, other types of functionality tests can be performed. For vibrating wire piezometers, they can be lowered in a borehole or a tube containing water and raised over a certain length while confirming that the readings of the piezometers indicate an equivalent change of water head.

Some instruments require taking an initial reading prior to installation as the quantity to be measured is very often calculated as the difference between a current reading and an initial reading. A valid initial reading is therefore vital for the future accuracy of the monitoring program. In some cases the user may not yet be fully familiar with the instrument and possibly the readout method at the time of taking the initial reading. Often it is critical to incorporate into the contract that a representative from the supplier or the manufacturer either be on-site or available by telephone for consultation during the installation and calibration.

6.5 Installation

It is important that installation be completed by those experienced in similar installations. Qualifications required of personnel installing instrumentation are critical to obtaining accurate and meaningful data. For electrical instruments such as vibrating wire, previous experience with same or similar instruments, as well as computer hardware and software skills are required. For instruments installed in boreholes, drillers should have appropriate experience placing standpipes, instruments, grouting and/or backfilling. Construction laborers and craft personnel (electricians, pipefitters, etc.) are sometimes used, but in all cases the installation should be closely monitored and documented by experienced, qualified personnel.

Relative movement device for three directions on a concrete joint requires precision installation

Reports documenting installation are essential, as it will be necessary to refer to the installation details later in time to explain some unexpected or unusual behavior of an instrument or conversely to confirm the validity of an instrument's readings. Installation reports should contain details of location; serial numbers of installed instruments; identification (ID) assigned to instruments; initial calibration readings; initial field

readings with associated data (e.g. headwater and tailwater elevations, temperature, antecedent rainfall, weather conditions).

Proper training on the installed instruments, readout method, troubleshooting and maintenance should take place at the time of installation as the main interested parties are generally present on site including the owner's representative and instrumentation manufacturer or installation firm.

During installation, consideration should be given to protecting instrumentation from vandalism, maintenance activities, and new construction that may occur near the instrument. This includes protecting riser (stand) pipes, survey markers, etc. from damage caused by mowing, drilling, local traffic, and potential theft or vandalism. It is recommended to install lockable covers over instruments to prohibit vandalism, especially to piezometer riser pipes, inclinometer casing, etc.

Proper identification should be incorporated on instrument components to facilitate identifying them in the future for readings and maintenance. All identifying information should be concise and updated when necessary to help identify and troubleshoot, especially when personnel in the future may not have been involved with the initial installation. All cable connections should be labelled with permanent marking to facilitate future identifications. Where available, it is recommended that identifying labels be placed on concrete markers closest to the instrument (especially to identify items that may be recessed and hard to label otherwise) or on label makers that leave an impression on material that won't disintegrate from sunlight or moisture over time.

Prior to travelling to the site to install components, a pre-trip checklist should be conducted to ensure all necessary items (tools and equipment) are included and accounted for prior to installation. This checklist should include an inventory of all tools needed to assemble, install, and test the instrument components, and perform a check of readings before leaving the field site. The checklist should also include a mock setup to see how the instrument will be powered, what tools it will take to install it, run signal cabling (where appropriate), make connections, and perform a field calibration. Such a checklist can help identify who, where, and how power and water connections will be located or provided before arriving onsite and realizing those resources may not be readily available.

7.0 SUMMARY

This paper is presented to aid dam owners in the development of an effective program of monitoring dams with instruments to ensure public safety. There are many considerations to achieve an effective instrumentation program; some key points presented include:

1. The establishment of standard procedures require that personnel must have clearly defined roles and responsibilities.
2. Instruments must answer a specific question or monitor an identified potential failure mode of the dam or foundation.

3. Selection of instruments for a project should be a thoughtful and thorough process; the Potential Failure Mode Analysis provides a formal and structured process to aid in selection.
4. The key qualifications of people working within the program are a strong motivation for safe operation of dams and a basic understanding of their design and performance.
5. A sufficiently funded instrumentation monitoring program is vital for the maintenance and safe performance of dams.
6. Attention to details in procuring and installing instruments is of utmost importance to successfully implement a dam safety instrumentation program.

8.0 REFERENCES

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