Chapter 10
Instrumentation

10-1. General

a. Introduction. All Corps of Engineers embankment dams should have an adequate level of instrumentation to enable design engineers to monitor and evaluate the safe performance of the structures during the construction period and under all operating conditions. This includes all appurtenant structures and facilities whose failure or malfunction would cause or contribute to loss of life, severe property damage, or loss of function or interruption of authorized mission. Instrumentation is not a substitute for an inadequate design. It is a tool to monitor and verify the performance of the design as constructed. The responsible district command should ensure the following:

(1) An appropriate level of instrumentation exists at each project.

(2) Adequate maintenance is programmed and accomplished.

(3) A sufficient level of effort and funding is devoted to the program.

(4) A timely reduction, interpretation, and evaluation of the data occur.

(5) This information is incorporated into a project performance evaluation.

(6) Monitoring results are permanently documented and made available for appropriate action.

The information that follows is described for embankment dams and levees. Similar concepts can and should be used on appurtenant structural features that are critical to project performance such as spillways, intake towers, walls, and control bridges.

b. Dam safety. In view of concerns for dam safety, it has become increasingly important to provide sufficient instrumentation in earth and rock-fill dams for monitoring the performance of the structure during construction, and for all anticipated stress conditions throughout the operational life of the project. Visual observations and the interpretation of instrumentation data from the embankment, foundations, abutments, and appurtenant features provide the primary means for engineers to evaluate dam safety. In recent years, technology of devices for measuring seepage, stresses, and movements in dams has improved significantly with respect to accuracy, reliability, and economics. These technologies should be used to the extent necessary to acquire sufficient information within the required timeframe to assure the thorough understanding of dam performance. Guidance on the selection and use of various types of instrumentation is presented in EM 1100-2-1908, Parts 1 and 2.

10-2. Instrumentation Plan and Records

a. General. The planning, design, and layout of an instrumentation program are integral parts of the project design. Instrument data are an extremely valuable asset that supplies an insight into the actual behavior of the structure relative to design intent for all operating conditions, establishes performance that is uniquely characteristic to the dam, and provides a basis for predicting future behavior. As structures age and new design criteria are developed, the historical data provide most of the information necessary to evaluate the safety of the structure with respect to current standards and criteria. Older structures may require additional instrumentation to gain a satisfactory level of confidence in assessing safe performance. Instrument data can be of benefit only if the instruments consistently function reliably and the data values are compared to the documented design limits and historical behavior. Automation of dam safety instrumentation is a proven, reliable approach to obtaining instrument data and other related condition information. Automation offers a feasible alternative to obtaining routine data that may not otherwise be obtained because of funding constraints, staff reductions, or inaccessibility. Automation can also be helpful with investigating and analyzing performance conditions that require frequent, timely, and accurate information that cannot be feasibly collected manually. It is recognized that automation technology evolves rapidly, and this specialized expertise is not resident at all districts. Assistance with automation is available through The Corps of Engineers Center for Automated Performance Monitoring of Dams, reference ER 1110-1-8158.

b. System design. The design and construction of new projects as well as the rehabilitation, dam safety modifications, and normal maintenance of older projects present opportunities to prepare for the future engineering analyses of structural performance. Careful attention and detail should be incorporated into the planning of instrumentation systems and programs to ensure that the required information is obtained. As a minimum, the parameters that are critical to satisfactory performance (see Appendix E) will dictate the selection of instrument types. Ideally, instrument systems will include some degree of overlap and/or redundancy to enable verification of problems that may be detected. Appropriate instrument devices are selected to provide the engineering measurements to the magnitude, precision, and response time necessary to evaluate the parameters. Generally, the types of measurements are as follows:

(1) Horizontal and vertical movement.

(2) Alignment and tilt.

(3) Stresses and strains in soil and rock fill.

(4) Pore pressure.

(5) Uplift pressure.

(6) Phreatic surfaces.

(7) Seepage clarity and quantity.

In all circumstances, background information that may affect the validity of the data or the analysis of the performance (such as hydrologic or weather conditions) is documented and baseline instrument data for each type of measurement is obtained for future comparison. Other considerations include the potential damage resulting from construction or vandalism, effects of a severe environment on the instruments, and maintenance and personnel requirements for data collection and evaluation.

c. Installation and maintenance. Instrumentation for a project should be included in the design phase, during construction, and throughout the operational life of the project as conditions warrant. After a project has been operational for several years, appropriate maintenance, repair, and replacement of instrumentation must be accomplished during the normal operation to assure continued data acquisition and analyses of critical performance parameters. Specific guidance for maintenance, rehabilitation, and replacement can be found in EM 1110-2-1908. Note that specialized expertise may be required to install and maintain automated instrumentation.

d. Data collection, interpretation, and evaluation. The frequency with which instrumentation data are obtained must be tailored to the monitoring purpose, period of construction, investigation, or other interest, and project operating conditions. In all cases, sufficient calibration must be performed and background data must be obtained to ensure that a valid and reliable database is developed, maintained, and available to facilitate subsequent comparisons. After a baseline of performance is established, the subsequent reading of instruments during construction and operating conditions should be based on an anticipated rate of loading or changes in reservoir levels. The timely reduction and interpretation of instrumentation data are essential for a responsive safety evaluation of the project. For all Corps projects, this reduction, interpretation, and evaluation should occur as soon as conditions warrant after the data were obtained. The evaluation of the data should follow immediately. As a minimum, all data should be plotted as instrument response with respect to time, as well as reservoir level or other range of loading. More detailed guidance for data acquisition, interpretation, evaluation, and presentation is in EM 1110-2-1908.

e. Documentation. Information relative to instrumentation systems is an invaluable resource that is necessary to evaluate instrument and system performance, as well as influence the assessment of dam performance and should be preserved and readily accessible. Such information includes, but is not limited to, installation reports, testing results, modification to the sensors or system components, maintenance records, manufacturers performance specifications, warrantees, and other information.

10-3. Types of Instrumentation

The type, number, and location of required instrumentation depend on the layout of the project and the construction techniques employed. Devices may consist of the following: piezometers (open tube, such as the Casagrande type, electrical, vibrating wire, or occasionally closed systems) located in the foundation abutment and/or embankment, surface monuments, settlement plates within the embankment, inclinometers, movement indicators (at conduit joints, outlet works, and intake tower), internal vertical and horizontal movement and strain indicators, earth pressure cells, and accelerographs (in areas of seismic activity).

10-4. Discussion of Devices

a. Piezometers. The safety of a dam is affected by hydrostatic pressures that develop in the embankment, foundation, and abutments. Periodic piezometer observations furnish data on porewater pressures within the embankment, foundation, and abutments, which indicate the characteristics of seepage conditions, effectiveness of seepage cutoff, and the performance of the drainage system. The installation should consist of several groups of piezometers placed in vertical planes perpendicular to the axis of the dam so that porewater pressures and/or seepage pressures may be accurately determined for several cross sections. At each cross section that piezometers are placed, some should extend into the foundation and abutments and be located at intervals between the upstream toe and the downstream toe, as well as being placed at selected depths in the embankment. In addition to the groups of piezometers at selected cross sections, occasional piezometers at intermediate stations will provide a check on the uniformity of conditions between sections. Each piezometer should be placed with its tip in pervious material. If pervious material is not present in the natural deposit of foundation material, or if the tip is in an impervious zone of the embankment, a pocket of pervious material should be provided. Two of the more important items in piezometer installation are the provision of a proper seal above the screen tip and the water tightness of the joints and connections of the riser pipe or leads.

b. Surface monuments. Permanent surface monuments to measure both vertical and horizontal alignment should be placed in the crest of the dam and on the upstream and downstream slopes. Survey control should be maintained from offsite reference monuments located in stable material outside of the limits of influence from the construction and removed from the parameters being monitored. Monuments should be embedded in the embankment by means of a brass or steel rod encased in concrete to a depth regionally appropriate to avoid frost action. All monuments must be protected against disturbance by construction and maintenance equipment. Guidance on spacing is as follows: 50-ft intervals for crest lengths up to 500 ft, l00-ft intervals for crest lengths to 1,000 ft, and 200- to 400-ft intervals for longer embankments. These monuments should be installed as early as possible during construction and readings obtained on a regular basis.

c. Inclinometers. Inclinometers should be installed in one or more cross sections of high dams, dams on weak deformable foundations, and dams composed at least in part of relatively wet, fine-grained soils. Inclinometers should be installed particularly where dams are located in deep and narrow valleys where embankment movements are both parallel and perpendicular to the dam axis. Inclinometers should span the suspected zone of concern. It is essential that these devices be installed and observed during construction as well as during the operational life of the project.

d. Miscellaneous movement indicators. Various types of instrumentation may be installed to measure horizontal spreading of the embankment (particularly when the foundation is compressible), movements adjacent to buried structures, foundation settlement, and internal strains. Strain measurements are particularly significant adjacent to abutments and below the crest to detect cracking of the core. Where there is a possibility of axial extension, as near steep abutments, surface monuments should be placed on the crest at 50-ft intervals to permit measurement of deformations along the axis.

e. Pressure cells. The need for reliable pressure cells for measuring earth pressures in embankments has long been recognized, and much research has been done toward their development. Although many pressure cells now installed in earth dams have not proved to be entirely satisfactory, newer types are proving to be satisfactory and increased usage is recommended. Some types of pressure cells installed at the interface of concrete structures and earth fill have performed very well.

f. Accelerographs. For important structures in areas of seismic activity, it is desirable to install strong-motion, self-triggering recording accelerographs to record the response of the dam to the earthquake motion. ER 1110-2-103 provides requirements and guidance for installation and servicing of strong-motion instruments. EM 1110-2-1908 discusses types of devices and factors controlling their location and use. Digital accelerographs are recommended as replacements for existing analog film-type accelerographs. The digital units record and provide fundamental event information on a near real-time basis and should be incorporated into dam safety monitoring programs. A status report on Corps of Engineers strong-motion instrumentation for measurement of earthquake motions on civil works structures is provided annually. The monitoring of seismic activity at Corps dams is shared by ERDC, Vicksburg, MS, and the U.S. Geological Survey, depending on the geographic location of the dam. Dam Safety engineers should establish and maintain close coordination with the appropriate organization for seismic monitoring.

10-5. Measurements of Seepage Quantities

The seepage flow through and under a dam produces both surface and subsurface flow downstream from the dam. The portion of the total seepage that emerges from the ground, or is discharged from drains in the dam, its foundation, or abutments, is the only part that can be measured directly. An estimate of the quantity of subsurface flow from flow net studies may be based on assumed values of permeability. The portion of the seepage that appears at the ground surface may be collected by ditches or pipe drains and measured by means of weirs or other devices (monitoring performance of seepage control measures is discussed in detail in Chapter 13 of EM 1110-2-1901).

10-6. Automated Data Acquisition Systems

a. General. Developments in the field of electronics have now made it possible to install and operate automated instrumentation systems that provide cost-effective real-time data collection from earth and rockfill dams. Installation of these computer-based automated data acquisition systems (ADAS) provides for more accurate and timely acquisition, reduction, processing, and presentation of instrumentation data for review and evaluation by geotechnical engineers. Consideration should be given to providing an ADAS for all new dam projects, dam safety modifications to existing dams, and monitoring system rehabilitation that are necessary to assure appropriate data acquisition. General guidance for developing an ADAS is presented in Appendix D.

b. Conditions warranting automated data acquisition systems. The following are examples of conditions that would benefit from the use of an ADAS:

(1) The project is located in a remote area, or would be inaccessible during critical operating conditions.

(2) Limited staffing is required to perform other duties when extreme loading conditions exist, such as flood fighting or emergency response, and is not available for monitoring requirements.

(3) High frequency of data collection is necessary to help define complex or interrelated conditions.

(4) Rapid or immediate dam performance assessments are required.