Chapter 9
Continual Reassessment for Long-Term Monitoring

9-1. Introduction

This chapter addresses factors unique to long-term monitoring. Historical experience of dam designers, constructors, and engineers responsible for dam safety has shown first that: the function of a project changes with age, second that deterioration can be progressive with time, and third that problems can develop and occur at any time during the history of a structure. Engineers responsible for the dam safety of the embankment dams and levees must learn and understand the characteristic behavior of each embankment and other structure so that this knowledge can be applied in any future investigations, recommendations, and remedial actions. Ensuring safety is a continuing process, the responsibility for which must be accepted for the entire life of a project.

9-2. Long-term vs Construction-Related Instruments

The initial design of an instrumentation system should consider not only construction-related instruments, but also long-term instruments. Long-term instrumentation may be needed to provide data to validate design assumptions, to provide information on the continuing behavior of the foundation, embankment, or abutments, and to observe the performance of unique features. If deemed necessary, a well-planned system of instruments (see paragraph 3-6) should be installed to provide data on flows, pore water pressures, and/or deformations at structurally significant locations in the foundation, embankment, and/or abutments during construction, first filling, and long-term operation. A careful examination of instrumentation data on a continual basis may identify a new condition, or may play a role in reassuring the reviewer that an observed condition does not require immediate remedial measures.

9-3. Primary, Secondary, and Tertiary Instruments

The classification of instruments into primary, secondary, and tertiary categories usually relates to piezometers, but may apply to all other instruments installed at a project. Figure 9-1 illustrates an example of instrument classification and sample locations. The primary instruments include all instruments located along a typical cross section at or near the maximum structural vertical section. Also included are piezometers installed to monitor structurally significant features or suspect areas in the foundation, embankment, and/or abutments. Secondary instruments are those located in less critical sections or areas. Tertiary instruments include other instruments that have been installed to verify that other areas of the project behave in a similar way to the areas where the primary and secondary instruments are located. If automation is a consideration (see Chapter 5), the primary instruments would be the first to be included in the automation system.

9-4. The Evolving Instrumentation System

One of the early steps in the planning of an instrumentation system (see Chapter 3) is to define the geotechnical questions that need to be answered. For a long-term monitoring system, the questions that need to be answered are normally associated with developing trends over time and response under major pool conditions (which for a flood-control project may not occur for many years after construction). Construction-related instruments must not be maintained unless they can assist in answering long-term questions. Typical questions relating to long-term monitoring might be: *Is the feature responding as assumed in design under high pool conditions? Is the seepage flow increasing with time?*

a. Changing conditions. Design criteria or existing conditions can change. For example, filter criteria for a dam designed and constructed in the 1930's are no longer accepted. Additional piezometers might be warranted to verify that pore water pressures are constant and that core material is not being lost. Siltation of the reservoir can occur with time, affecting the hydraulic gradient of the structure.

b. Effects of aging. As an embankment dam or levee ages, new problems or concerns may develop. It may be necessary to instrument potential problem areas to verify that conditions are not deteriorating.

c. Reading schedules. Reading schedules may vary depending on locations of instruments and associated factors such as reservoir level.

9-5. Steps for Continual Reassessment

Paragraph 3-6 provides a step-by-step procedure for planning a monitoring program. These steps were designed for a new structure, but they also apply to an existing

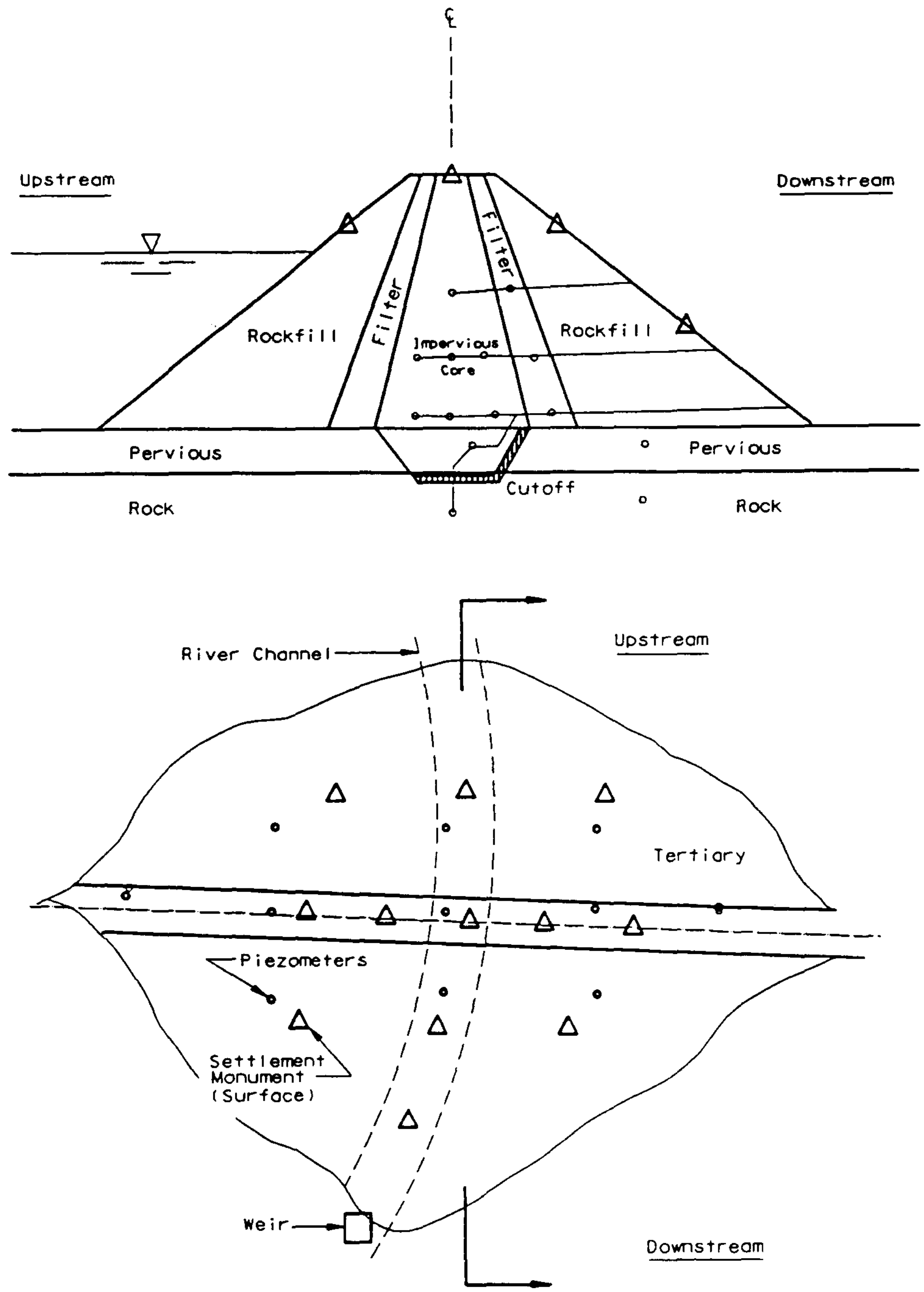

Figure 9-1. Instrument classification and sample locations

structure. The process for planning and executing a monitoring program for an existing structure should begin at the appropriate step. As with a new instrumentation system, the steps to follow for modifying or upgrading an existing system can vary, and are up to the discretion of the designer, or a senior-level geotechnical or instrumentation engineer. The terms *retrofit, rehabilitate, upgrade, and replace* have slightly different meanings with respect to instrumentation. The following paragraphs indicate these differences.

a. Retrofit. The term retrofit signifies changing or adding to an instrument that already exists. An example would be the installation of an electronic pressure transducer in an open standpipe piezometer.

b. Rehabilitate. The term rehabilitate is normally used in conjunction with the repair of an individual instrument or system. An example would be re-establishing a new initial for a settlement monument after the necessary repairs.

c. Upgrade. The upgrading of an existing instrument or system usually refers to the enhancement of a functioning instrument or system so that more reliable or frequent data can be obtained. The automation of existing instrumentation would be considered an upgrade. The upgrade of an instrumentation system may include the addition of instruments in order to monitor newly observed conditions.

d. Replace. Replacement signifies the installation of a new instrument or component and the abandonment of an existing instrument which cannot be repaired. It can also refer to the removal of a malfunctioning component, which is sent in for repair, replacement, or the installation of a spare part.

9-6. Selection of Parameters to Monitor

Table 9-1 gives, in priority order, measurements which are applicable for the long-term monitoring of embankment dams and levees, together with recommended instruments. It must be restated that the selection of instruments is dependent upon the unique characteristics of each structure or associated feature. For example, lateral subsurface deformation within a typical embankment dam will be less important than monitoring seepage, but it may be more critical in a potentially unstable abutment. Pore water pressures and subsurface settlement may rank higher if core material was placed and compacted too wet.

a. Visual observations. Dr. Ralph Peck has often stated that the human eye attached to an intelligent brain is the single most important instrument at a project site. Automation is sometimes criticized because of a concern that visual observations will not be made. The solution is to schedule regular visual inspections of all areas of a project, and not to rely solely on the automation equipment and instruments for warnings of potential problems. Moreover, if a major problem were to occur, it is very possible that the instruments in place would not give enough advance warning, simply because the instruments may not be located close enough to the problem area to detect the change, or simply because of the delay in data processing and review.

b. Seepage. Regular monitoring of seepage which appears downstream of an embankment dam or abutment is essential in assessing the behavior of a structure, not only during first filling, but also for monitoring long-term trends (see paragraph 4-8). The long-term monitoring should also include solids content. Relief wells for dams or levees have specific problems associated with the plugging of the filter packs or the accumulation of bacteria or carbonates (see EM 1110-2-1914). It is often necessary to install piezometers adjacent to relief wells to carefully monitor the pressure increases associated with clogged wells.

c. Pore water pressures within the embankment or abutments. For long-term monitoring, pore water pressures are measured in embankments or abutments to verify design assumptions and to monitor changes which could be an indication of a deteriorating core or stratum. Paragraph 4-3 includes a discussion of the various types of piezometers. The most reliable type for long-term monitoring is the open standpipe, possibly retrofitted with a retrievable transducer.

d. Seismic instrumentation. Seismic instrumentation is often installed at medium to large dams to guide decisions on remedial actions which may be necessary if a structure has been affected by a seismic event. Also the data can be a very important research tool, benefitting the design of future projects.

e. Vertical deformation. Measurements of surface settlement and horizontal movement at various points along the crest and on the slopes should be considered for monitoring long-term deformations. Measurements of subsurface vertical deformations can be of importance especially for large dams or for structures located on unique or soft foundations. Liquid level gages, horizontal inclinometers, subsurface settlement points, and probe exentsometers can all be used, depending on the circumstance (see paragraph 4-3).

f. Lateral deformation. Measurements of surface lateral deformations may be required, but they can often be terminated within a few years after first filling unless special conditions exist. Similarly, subsurface lateral

Table 9-1
Measurements and Instruments for Long-Term Performance Monitoring

Measurement, in Priority Order	Recommended Instruments
Condition of entire structure	Visual observations
Seepage	Seepage weirs or flumes Precipitation gage Pool elevation
Pore water pressure[1]	Open standpipe piezometers Twin-tube hydraulic piezometers Vibrating wire piezometers Pneumatic piezometers Electrical resistance piezometers
Seismic events	Strong motion accelerographs Microseismographs
Surface vertical or lateral deformations	Surveying techniques Global positioning system
Subsurface vertical or lateral deformations	Liquid level gages Inclinometers Extensometers Subsurface settlement points
Total stress at structure contacts	Contact earth pressure cells

[1] Listed in priority order, vibrating wire, pneumatic, and electrical resistance piezometers are only used in special cases.

Source: Dunnicliff (1988).

deformation measurements may be required only if there are special concerns. Probe extensometers, fixed embankment extensometers, and inclinometers are options for monitoring subsurface lateral deformation (see paragraph 4-4).

g. Additional instrumentation. Thermotic survey/ thermal monitoring (see paragraph 4-8*f*) of seepage water can be a useful tool for the long-term monitoring of seepage paths within an embankment or abutment. Temperature measurements are especially suitable for abutments with nonhomogeneous soil conditions, allowing the monitoring of strata where the seepage is occurring. Earth pressure cells can be used but generally are useful only when contact pressures between an embankment and an appurtenant structure are required (see paragraph 4-5).

h. Associated parameters. Various other parameters are often monitored. The purpose for monitoring reservoir, tailwater, and river levels needs no explanation. Rainfall affects surface runoff, which in turn affects weir and flume measurements. Air and water temperatures can affect transducer readings, and these measurements are also necessary as part of groundwater thermal studies. Barometric pressure can also affect certain transducer readings. Other conditions should always be noted when possible, such as general weather conditions and construction activities in the area. Reviewers are often searching for possible causes for unexplainable readings, and answers can often be found if the miscellaneous data are recorded.

9-7. Management

a. Data collection schedules. Data collection schedules must be reviewed within a few years after first filling. The number of instruments read at unchanged frequencies should generally be reduced to a few primary instruments. Readings of other instruments should either continue on a reduced schedule or be terminated. For example, the frequency of piezometer readings within a dam with a rapidly fluctuating pool should be more frequent than the pool cycle. If the pool elevation can cycle dramatically within a few days, a monthly reading schedule for the piezometers and seepage instruments may be useless. However, depending on the feature being monitored and the complexities involved, the original monitoring schedule may have to be continued for the life of the project for numerous instruments. In summary, the reading schedule should be matched to the conditions. Chapter 7 includes additional information.

b. Maintenance. The maintenance of instruments and automation equipment must be scheduled and budgeted for annually. Additional guidance is included in Chapters 5 and 8.

c. Data collection. The manual reading if instruments over the long-term has historically been difficult. Available project labor is becoming scarce, and when labor is available, temporary or untrained personnel are often used. Rapid turnover of temporary personnel makes training difficult. Despite the problems, quality of readings and observations must be maintained. The options available are dependent on the project, personnel, and required reading frequencies. Options can include the automation of instrument and/or the permanent hiring of an instrumentation technician. Paragraph 3-8*c* includes additional information.

d. Data processing and presentation. This topic is discussed in detail in Chapter 7. For long-term monitoring purposes, the data processing and presentation capabilities should be available at the project as well as in the District office. This allows personnel to respond to a major event more effectively, especially if communication to the District is affected. In addition, a complete record of instrumentation in plot format should be maintained at each project office. Historical data must be maintained for the life of the project.

e. Data interpretation, reporting, and analysis. Review and analysis schedules are dependent upon the individual projects and features. Minimum schedules are given in ER 1110-2-100 and ER 1110-2-110. Additional guidance is included in Chapter 7.