V. DAM SAFETY, INSTRUMENTATION AND SURVEILLANCE

5.1. Introduction

Reservoirs constitute a potential hazard to downstream life and property. The flood plain is at risk in the event of catastrophic breaching may be extensive, densely populated and of considerable economic importance. In such instances dam failure can result in an unacceptable loss of life and damage.

- Cases of catastrophic failures
    - Malpasset (France, 1959)
    - Vaiont (Italy, 1963)
    - Teton (USA 1976), etc.

Catastrophic failure of a dam, other than as a direct result of an extreme flood event, is invariably preceded by a period of progressively increasing structural distress within the dam and/or foundation. Dam surveillance programs and instrumentation are intended to detect and, where possible, to identify symptoms of distress at the earliest possible stage.

- Instruments strategically placed within or on a dam are not of themselves a safeguard against serious incident or failure. Their prime function is to reveal abnormalities or adverse trends in behavior, and so to provide early warning of possible distress.

- Numbers of instruments installed are of less importance than the selection of appropriate equipment, its proper installation, at critical locations and intelligent interpretation of the resulting data within an overall surveillance program.

5.2. Instrumentation

5.2.1 Application And Objectives

Monitoring instruments are provided in almost all new dams and basic level of instrumentation to monitor existing dams.

- In new dams, instrumentation data are interpreted to provide an indication of the validity of design assumptions and to determine an initial datum pattern of performance against which subsequent observations can be assessed.
- In existing dams (particularly elderly or less adequate structures) instruments are installed to provide a measure of reassurance, i.e. they serve to detect significant and abnormal deviation of the dam behavior in the long-term. They are also used to record specific parameters of behavior in response to suspected design deficiency or behavioral problem.

Planning and commissioning of instrumentation should be handled by relatively senior and experienced personnel within responsible organization. The primary function of instrumentation may be for:

(a) **Construction Control**: Verification of critical design parameters for feed back to design and construction.

(b) **Post-construction performance**: Validation of design; determination of initial or datum behavioral pattern.

(c) **Service performance/surveillance**: Reassurance of structural adequacy; detection of regressive change in established behavior pattern; investigation of identified or suspected problems.

(d) **Research/Development:** Academic research; equipment proving and development.

There are possible overlaps between certain of the functional classifications.

5.2.2. Parameters in Monitoring Dam Behavior

The most significant parameters in monitoring dam behavior are:

1. Seepage and leakage (quantity, nature, location and source)
2. Settlement and loss of freeboard in embankments (magnitude, rate)
3. External and internal deformation (magnitude, rate, location)
4. Pore water pressure and uplift (magnitude, variation)
5. Internal stress or pressure (magnitude)

Certain key parameters are of primary concern regardless of the type of dam considered, e.g. Seepage and external movement or deflection; others are relevant to a specific type of dam, e.g. Pore water pressures in relation to earth fill embankment dams.

The desirable minimum provisions for monitoring and surveillance on all dams should account for the measurement of seepage flows and crest deformations. Table 5.1 shows parameters and instruments employed.

Table 5.1 Primary monitoring parameters and their relationship to possible defects

Parameter	***Instruments***	***Measurement***	***Illustrative defect***	***Dam type***
Seepage	Drains-underdrains to V-notch, weirs (ideally several, ‘isolating’ sections of dam-foundation)	Seepage flow quantity, and nature of seepage water, e.g. clear or turbid	Could indicate initiation of cracks and/or internal erosion	E, C[a]
Collimation	Precise survey (optical or electronic)	Alignment	Movement	E, C
Porewater pressure	Piezometers	Internal water pressure in earthfill	Leaking core, or incipient instability	E
Uplift	Piezometers	Internal water pressure in concrete or rock foundation	Instability, sliding	C
Settlement	Precise survey (surface)	Crest settlement	Tilting (C) or loss of freeboard (E), e.g. core subsidence, or foundation deformation	E, C
	Settlement gauges (internal)	Internal or relative settlement		
External deformation	Precise survey (surface) Photogrammetry(E), pendula or jointmeters	Surface deflection	Local movement, instability	E, C
Internal deformation or strain: - vertical - horizontal	Inclinometers, strain gauges or duct tubes	Internal relative movement	Incipient instability	E
Stress or pressure	Pressure cells	Total stress	Hydraulic fracture and internal erosion	E

[a]E = embankment dams, C = concrete dams

4.3.3. Instruments: Design and Operating principles

Monitoring instruments are required to function satisfactorily under very harsh environmental conditions and essentially for indefinite period of time. Therefore, a desirable instrument must be:

(a) as simple in concept as is consistent with their function
(b) robust and reliable
(c) durable under adverse environmental and operating conditions and
(d) acceptable, through-life cost (i.e. sum of purchase, installation, and monitoring cost).

A comprehensive detail of the various equipment, their operating principles and characteristics should be referred to, which could be provided by manufacturers or qualified society/Authors.

5.2.4 Instrumentation Planning

The planning and specification of a comprehensive suite of instruments involves a logical sequence of decisions:

(a) Definition of the purpose and objectives (why? and what?);
(b) Definition of observations appropriate to the dam considered;
(c) Determination of the locations and numbers of measuring points for the desired observations;
(d) Consideration of the time period to be spanned, i.e., long-or short-term monitoring;
(e) Consideration of the optimum sensing mode in relation to the desired rapidity of response, required accuracy; etc.
(f) Selection of hardware appropriate to the task as defined under a-e.

Step (c) is one of particular importance and sensitivity. Instruments must cover known critical features of the dam; but should also be placed at locations where 'normal' behavior may be anticipated. In new dams, at least two sections should be instrumented, including the major section. It is good practice to draft an ideal layout in the first instance, and then to progressively eliminate the less essential provisions until an adequate, balanced and affordable plan is determined.

It is advisable to consider instrumentation program in terms of the overall ‘system’ required, i.e. instruments, installation, commissioning, monitoring, and data management and interpretation.

The following figure shows a representative instrumentation profile for a new earthfill embankment (Fig. 5.1)

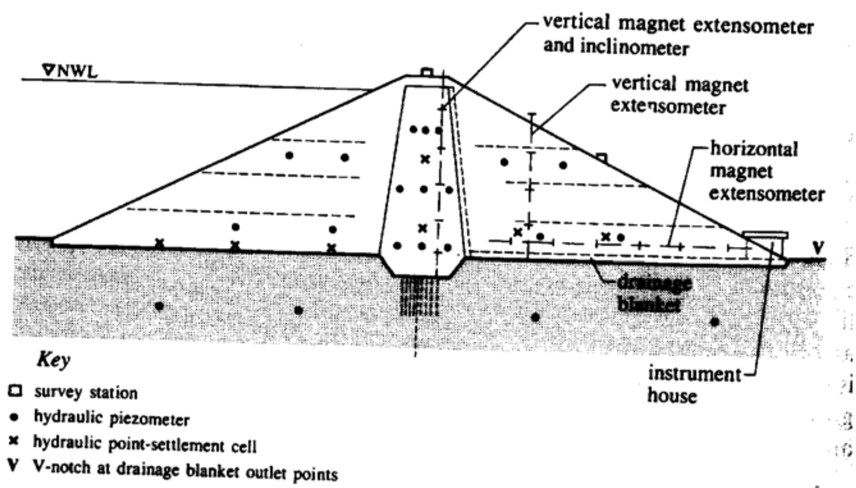

Figure 5.1 Representative instrument layout: major section of a new embankment dam

5.2.5 Data Acquisition and Management

Logical planning of data acquisition and processing is essential if the purpose of an instrumentation program is to be fully utilized. Unless observations are reliable and the information is interpreted quickly the value of the program will be severely diminished.

Within the operating plan the frequency of monitoring should be determined on a rational basis, reflecting the objectives and the individual parameters under scrutiny. Detailed prescription of periodicity is a question of common sense and engineering judgment.

- An excess of data will prove burdensome & may confuse important issues; too little information will raise more questions than it resolves. It should not also be too complex system (in terms of equipment or operating skills required)-should be responsive and flexible system.

As an example, the following table shows representative monitoring frequencies for embankments.

Parameter	Frequency
Water level	Daily wherever possible
Seepage	Daily or weekly
Piezometers	Once or twice weekly (construction) to three to six monthly (routine)
Settlement-deformation	Daily (suspected serious slip) to three to six monthly (routine)

5.3 Surveillance

Dams of all types require regular surveillance if they are to be maintained in a safe and operationally efficient state.

The primary objective of surveillance program is to minimize the possibility of catastrophic failure of the dam by timely detection of design inadequacies or regressive changes in behavior. A further objective is to assist in the scheduling of routine maintenance or, when necessary, of major remedial works.

Surveillance embraces the regular and frequent observation and recording of all aspects of the service performance of a dam and its reservoir. It includes routine observation and inspection, the monitoring and assessment of seepage and instrumentation data and the recording of all other relevant information, including hydrological records. Less frequent but more rigorous statutory inspections by specialist engineers are also carried out as part of a comprehensive surveillance program and may include a complete investigation reappraisal of the dam's integrity.

For the purpose of describing necessary surveillance activities, many of which are interdependent, five critical phases in the life cycle of a dam must be identified:

1) **The design or pre-construction phase**
   - Assessments must be made of the conditions that can be imposed upon the structure by its boundary environment or those existing conditions affected by the structure.
2) **The Construction period**
   - When opportunity for verifying design predictions is available, the accuracy of the design assumptions often revealed, and the initial effects of structural loading can be assessed.
3) **The period of first reservoir filling**
   - When the impact of hydraulic loading and reservoir induced seepage effects can be initially observed & assessed.
4) **The early operation period of the dam**,
   - When the structure is subjected to an increased range of operating /loading conditions, and the time dependent effects of the reservoir reaching equilibrium.
5) **The subsequent aging of the operating structure and its infrequent exposure to extremes of hydraulic and seismic external loading.**