INSTRUMENTATION AND MONITORING OF DAMS AND RESERVOIRS

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Contents

Summary

Instrumentation and monitoring of dams and reservoirs are important concerns in dam engineering. At each stage of investigation, planning, design, construction and operation in dam engineering, instrumentation and monitoring are required to monitor the behavior of engineering points. Their performance during both construction and operation are aimed at safety of dams and acquiring information to be used in progressing future design of dams. Instrumentation and monitoring are necessary in both the reservoir and the river basin, for normal operation and safety.

1. Introduction

For the safety and normal operation of a dam, precise information is required from instrumentation and monitoring of dam's body, the surrounding foundations, the reservoir and the river basin. Their behavior during each stage of investigation, design, construction and operation are very important information for engineering decisions.

Different kinds of instrumentation and monitoring are required for the different types of dam, reservoir and river basin.

2. Purpose of instrumentation and monitoring

After their construction, instrumentation and monitoring of dams fall into two broad categories: instrumentation and monitoring of the dam body, and of the reservoir and the catchment area.

2.1. Dam body

Instrumentation and monitoring of dam bodies serves two purposes: assessment of dam safety, and improvement of design procedures and practice for future dams.

Monitoring for assessment of safety

Although dams are constructed with great attention to detail following careful survey, design, and construction stages, a number of serious dam accidents have occurred in the world. It is therefore important to monitor the behavior of each dam during subsequent operation of the reservoir to assess its safety on a continual basis.

Monitoring for improvement of design procedures and practice for future dams

Various assumptions regarding physical properties and loading conditions are made when designing dams. It is therefore desirable to improve design procedures based on the measurement of deformation, stress, and other behavior. This type of measurement is carried out for selected dams.

2.2. Reservoirs and catchment areas

In contrast to the measurement and monitoring of dam bodies, those of reservoirs and catchment areas are conducted for the purpose of appropriate operation and management of dams. Items for observation and survey include reservoir level, sedimentation, rainfall, water quality, and ecology.

3. Instrumentation and monitoring for the assessment of dam safety

3.1. Items of monitoring

Items of monitoring for dam safety are selected according to the scale and condition of each dam. Fundamental items are:

- Concrete dam: leakage, deformation, uplift pressure, earthquake motion.
- Embankment dam: leakage, deformation, pore pressure (seepage line), earthquake motion.

3.2. Instruments monitoring systems

The parameters to be measured, and the appropriate instruments, are as follows:

- Leakage or seepage losses: drainage holes, V-notch weirs.
- Deformation (concrete dam): plumb lines, external targets.
- Deformation (embankment dam): differential settlement gauges, external targets.
- Uplift pressure: Borden tubes, piezometers.
- Pore pressure: piezometers.
- Earthquake motion: strong motion seismographs.

Different types of gauges are used including those of strain-gauge-type, differential-transformer-type, and vibrating-wire-type.

The most commonly used instruments are outlined in Figure1.

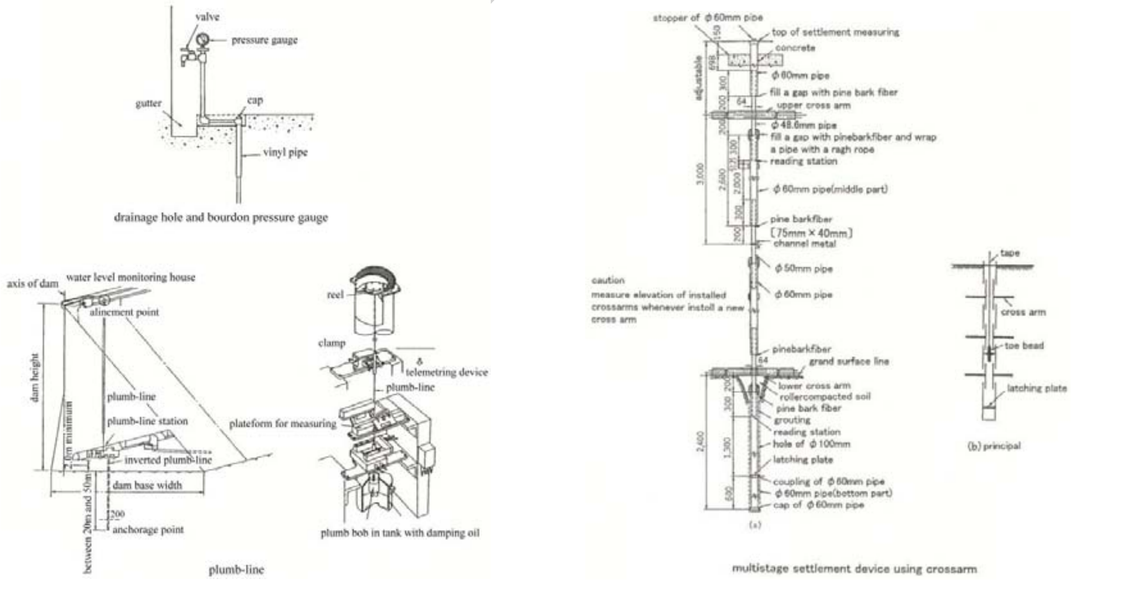

Figure1. Examples of instruments

Considerations for selection of instruments

When selecting instruments, the following requirements must be taken into consideration:

- precision is within the acceptable range;
- operation is easy;
- durability is high, and
- repair and replacement are possible.

3.3. Evaluation of measurements

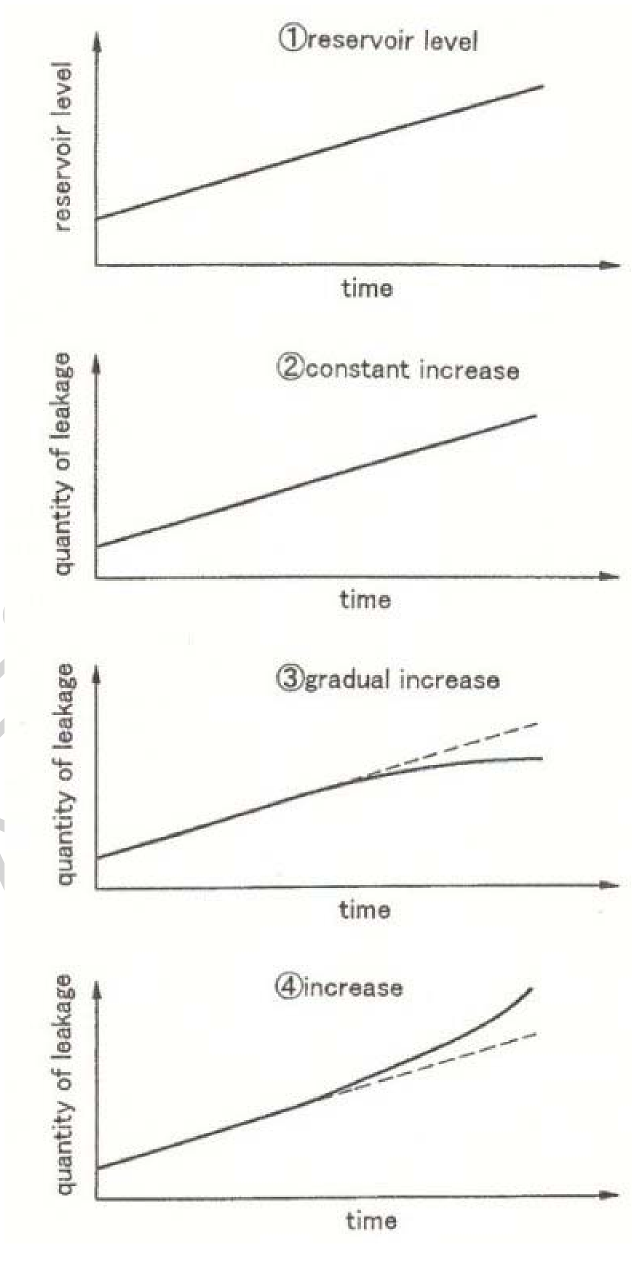

Figure 2. Change of leakage with increasing reservoir level

Variation with time

Variations in measurements with time are investigated for the purpose of appropriate safety control.

Regardless of the type of dam, the most basic and important measurement item for safety control is leakage from the foundation rock, as described below.

Typical patterns of increase in leakage in response to increase in reservoir level after the start of filling are shown in Figure2. A stable situation can be assumed if the rate of increase remains constant (2) or decreases gradually (3). Close attention is required if the rate of increase rises abruptly (4).

Relationship between leakage and reservoir level

After measurements have been accumulated to some extent, trends can be seen more clearly by focusing on leakage at constant reservoir level (Figure 3). A stable situation can be assumed when leakage decreases gradually (1) or remains nearly constant (2). Causes must be identified if leakage increases gradually (3), and countermeasures must be taken urgently if leakage increases abruptly (4).

In the first filling of the reservoir, however, accumulation of measurements may not be sufficient and the period of constant reservoir level is generally short. Therefore, investigation of the trend of leakage at constant reservoir level, as depicted in Figure 3, is often difficult. In such a case, a correlation diagram with reservoir level on the vertical axis and measured leakage on the horizontal axis may be drawn to check for any abrupt changes in the trend. An example of such a correlation diagram in a case study is presented later in this chapter.

Time after the start of filling, and measurement items and frequencies

Past incidents of dam accidents indicate that the first filling of the reservoir is the most important period of safety control. Dams that experienced accidents during the first filling include the Malpasset Dam (France, completed in 1954, burst in 1959) the Viont Dam (Italy, completed in 1960, overflowed as a result of a landslide into the reservoir in 1963), and the Teton Dam (USA, completed in 1975, burst in 1976).

In a normal situation, measurements of a specific item are expected to become stable with time as depicted in Figures 2 and 3.

It is therefore customary in safety control to measure a greater number of items with greater frequencies during the first filling, and measure a smaller number of items with lower frequencies as the measurements become stable.

Other precautions

For safety control, not only the amount but also the turbidity of leakage is important.

The turbidity of leakage observed at the drainage holes set up in the inspection gallery of a dam body and at the ground surface downstream may indicate local seepage failure in the foundation or the dam body.. When an increase in turbidity is observed, close attention should be paid, even if leakage is small at the time.

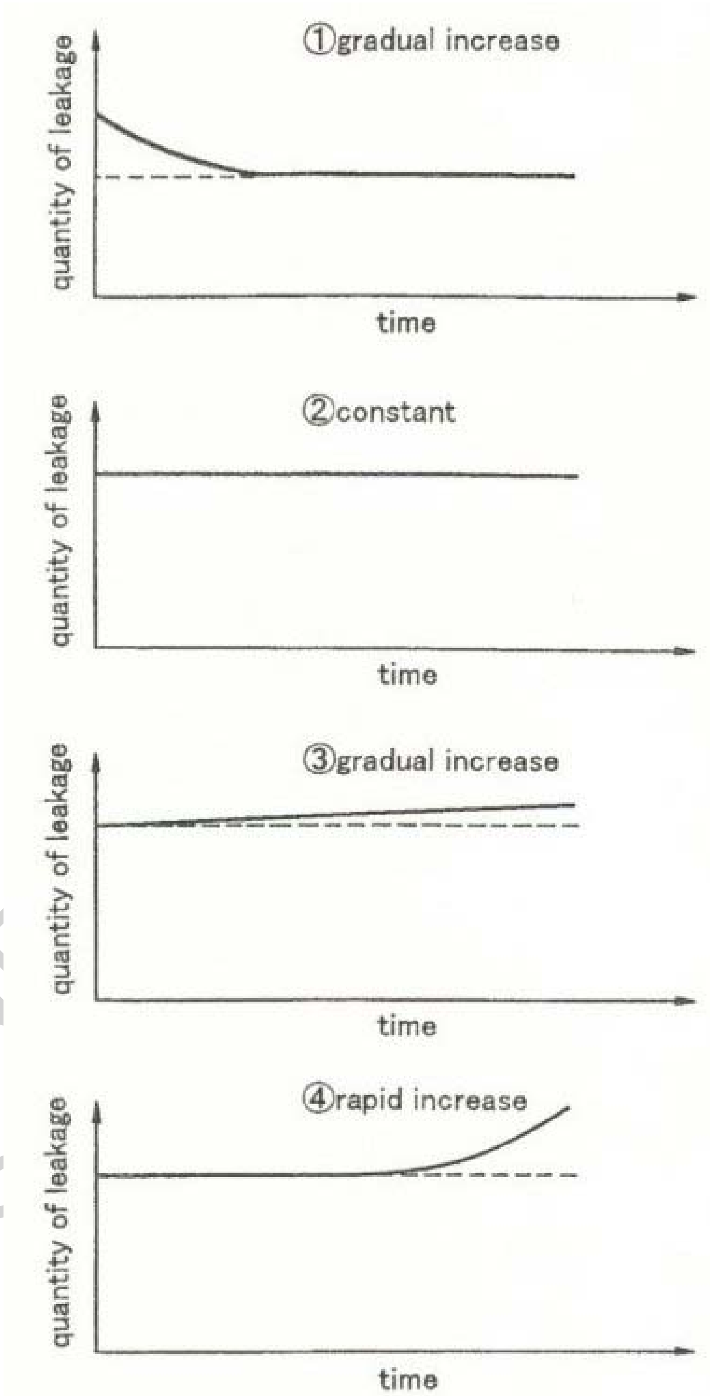

Figure 3. Change of leakage at constant reservoir level

4. Monitoring for improvement of design procedures and practice for future dams

4.1. Items of monitoring

Monitoring for improvement of design procedures and practice for future dams are performed to verify the adequacy of design and analysis methods including design loads.

Parameters to be monitored are as follows:

- Concrete dam: stress, strain, temperature, uplift pressure, earthquake motion.
- Embankment dam: stress, strain, earthquake motion.

4.2. Instruments

Instruments other than those listed in Section 2 are as follows:

- Concrete dam: stress meters, strain gauges, thermometers.
- Embankment dam: earth pressure gauges, piezometer, internal displacement gauges.

Things to be considered when selecting instruments and evaluating measurements are basically the same as those discussed in Section 2. If improvement of design procedures is the only purpose, instruments may be allowed to become incapable of measurement after the collection of intended data. This means that buried instruments that cannot be repaired or replaced may be adopted.

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The following are examples of recommended materials published by ICOLD, which provide useful

information concerning dam monitoring.

Bulletin 41 (1982): Automated Observation for the Safety Control of Dams.

Bulletin 59 (1987): Dam Safety - Guidelines.

Bulletin 60 (1988): Dam Monitoring – General Considerations.

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Biographical Sketches

Mituaki Mizuno is the former executive director of Water Resources Development Public Corporation, Japan. He is versed in construction, operation and maintenance of dams. The Corporation had completed 23 dams by 2002 and is implementing the operation and maintenance of these. It is the biggest executive organization for water resources development projects in Japan. At present he is playing an important role as adviser in various fields of dams, as an expert dam engineer representing Japan. He has qualifications of a Professional Engineer in Japan.

Dr. Toshio Hirose is an honorary member of the Japan Society of Civil Engineers, the former Vice-Minister of the Ministry of Construction, the former President of the Japan Commission on Large Dams and the President of the Ecology and Civil Engineering Society. He is a top leader in dam engineering in Japan. He has experienced every stage of dam engineering, such as design, construction, operation for river management and also environmental countermeasures for reservoir by biotechnological conception. He originally proposed the Roller Compacted Dam (RCD) method of construction and applied it in actual projects. He established the Ecology and Civil Engineering Society aiming at close cooperation between civil engineering and ecology. It is organized by civil engineers and biologists from all fields such as algae, fishes, plants, invertebrates and birds. He is now actively involved in these fields.