APPENDIX 2

INSTRUMENTATION PLAN
(SAMPLE FRAMEWORK)

MARCH 2021

GOOD PRACTICE NOTE ON
DAM SAFETY

THE WORLD BANK
IBRD • IDA • WORLD BANK GROUP

GWSP
GLOBAL WATER SECURITY & SANITATION PARTNERSHIP
About the Water Global Practice

Launched in 2014, the World Bank Group’s Water Global Practice brings together financing, knowledge, and implementation in one platform. By combining the Bank’s global knowledge with country investments, this model generates more firepower for transformational solutions to help countries grow sustainably.

Please visit us at www.worldbank.org/water or follow us on Twitter at @WorldBankWater.

About GWSP

This publication received the support of the Global Water Security & Sanitation Partnership (GWSP). GWSP is a multidonor trust fund administered by the World Bank’s Water Global Practice and supported by Austria’s Federal Ministry of Finance, the Bill & Melinda Gates Foundation, Denmark’s Ministry of Foreign Affairs, the Netherlands’ Ministry of Foreign Affairs, the Swedish International Development Cooperation Agency, Switzerland’s State Secretariat for Economic Affairs, the Swiss Agency for Development and Cooperation, and the U.S. Agency for International Development.

Please visit us at www.worldbank.org/gwsp or follow us on Twitter #gwsp.
Appendix 2
Instrumentation Plan (Sample Framework)

Introduction

This sample framework of the Instrumentation Plan (IP) outlines the key elements, such as instrumentation monitoring system, program and data collection, analyses, and reporting. Annex A provides a sample table of contents for the IP.

The IP is one of four dam safety plans required for certain dams' by the World Bank Environmental and Social Framework/Environmental and Social Standard 4/Annex 1 on safety of dams, which include (a) Construction Supervision and Quality Assurance Plan (CSQAP), (b) IP, (c) Operation and Maintenance Plan (O&MP), and (d) Emergency Preparedness Plan (EPP). In the World Bank's project cycle, the IP is required before bid tendering as part of the dam's detailed design and bidding documents. Some descriptions of this note related to the procedure and frequency of monitoring data collection, processing, analyses, reporting, and maintenance works can be referred to or complemented by the O&MP.

Key Features of the Dam

Key features of the dam should be provided, including

- Purpose, type, height, crest length, reservoir capacity, and so on of the dam;
- Type and discharge capacity of spillway, outlet works, and so on, along with their operational modalities;
- Main features of associated facilities, such as power generation plant, water intake, and so on;
- Information on the reservoir and catchment area;
- Key potential hazards; and
- Location of the dam and access routes.

Purpose of Instrumentation

The primary purpose of instrumentation is to measure, collect, and analyze data of key physical parameters of a dam and associated structures in order to: (a) assess their performance and behavior, (b) detect potential defects and deficiencies at an early stage, and (c) verify that those structures perform according to the design.

1 As per ESS4 – Annex 1, para 2, these are “large dams” and “small dams” that could cause safety risks or are expected to become large dams during their operating life.
The IP should clearly state that the dam would install an adequate level of instrumentation to monitor and evaluate the safe performance of the dam and associated facilities during the construction and reservoir filling periods and throughout its operational life. Monitoring data should be analyzed and interpreted to detect anomalies and changes in dam performance that might indicate deterioration or malfunction of the dam structure and facilities as early as possible to enable a timely response. Although instrumentation cannot replace regular visual inspections, it would provide critical data for checking the dam’s performance and behavior. Instrumentation measurements can also be used to verify design assumptions and to identify whether potential failure modes are in progress. It is thus important to consider potential hazards and failure modes for designing a suitable instrumentation system for each dam.

Instrumentation Scope and Requirements

The scope and requirements of the instrumentation system should be tailor-made to the type and size of the dam, the mode of construction, and conditions and characteristics of the site. It is essential to carefully define the type, number, and specification of required monitoring instruments with due consideration to the particular condition of the dam, adequate coverage of phenomena linked to dam behavior, the required parameters to monitor, dam type and size, foundation condition, construction technique, instruments capacity and measuring range, the required degree of precision and level of reliability, installation arrangements, and so on.

A risk-informed approach should be taken to identify and determine the instrumentation requirements. This is achieved by identifying the ways in which failure or misoperation could occur. The instrumentation system should thus be designed to monitor the performance of the dam and key indicators of abnormal conditions leading to potential failure.

The instrumentation system should be simple, reliable, accurate, robust with minimum interface, and durable to withstand conditions during construction and normal operation, as well as potential vandalism. Sensors should be easy to install, calibrate, maintain, and operate. The system should include sufficient instrumentation for the measurement of parameters critical to dam safety and incorporate some redundancy in case of instrument failure and the cross-checking of results. The system may also consider introducing an automated monitoring system for the more frequent monitoring of key dam safety parameters, such as reservoir water level, piezometric levels, and seepage flows and turbidity level to improve quality and reliability of monitoring system.

Life-Cycle Management of Instrumentation System

The level of scrutiny of how the dam behaves under varying loading conditions should be highest in the initial phases of project life (first reservoir filling and initial years after commissioning). In that period, most of the engineering questions, from design to construction, will find partial or full answers; additional questions may arise during operation.

During the life of a dam, additional instruments may need to be installed to gain a satisfactory level of confidence in assessing dam safety. Additional instruments would normally result from dam safety
engineers’ identification of changing conditions, review of behavior, or recommendations arising from
dam safety inspections.

Instruments have different life periods; generally, those that can provide rapid response have shorter
lives. In the primary interest of safety, and in terms of operation reliability, it is essential that an adequate
monitoring and instrumentation system always be in place. As a minimum, and after validation during
the first reservoir filling, the essential monitoring in the long term should be ensured. For that end, an
adequate instrumentation system should balance rapid response and short living instruments with
more durable ones.

Based on design expectations, a life-cycle management plan should contain scenarios for system
revision and rehabilitation at preidentified periods along the life of the project. The IP should thus be
reviewed and updated periodically according to acquired experience.

**Instrumentation Monitoring Program**

**Typical Monitoring Indicators and Instrumentation Types**

Tables A.1 and A.2 provide key indicators that may require monitoring for concrete and embankment
dams, respectively. The typical type and location of instrumentation to monitor the key indicators are
also provided in the tables.

It should be noted that the instrumentation listed in these tables is not exhaustive and other key
indicators may require monitoring and should be tailor-made for each specific dam. Notably, dams in
high seismic areas should be equipped with accelerographs to record the response of the dam to the
earthquake motion at dam crest and at foundation level.

**Reading Frequency**

The typical reading frequency of monitoring instruments and surveillance activities are indicated in
table A.3. The frequency should be specified for each dam in consultation with qualified dam safety
experts considering the dam or foundation type, specific dam performance monitoring needs, potential
risk of the dam, and so on.

<table>
<thead>
<tr>
<th>Key indicator</th>
<th>Typical instrumentation type</th>
<th>Typical location of instrumentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplift pressure</td>
<td>• Uplift pressure gauge&lt;br&gt;• Vibrating wire piezometers</td>
<td>• Dam-foundation interface&lt;br&gt;• Dam foundations&lt;br&gt;• Dam-abutment interface</td>
</tr>
<tr>
<td>Seepage</td>
<td>• Weirs or flumes</td>
<td>• Dam downstream toe&lt;br&gt;• Abutment toe&lt;br&gt;• Inspection/drainage gallery</td>
</tr>
<tr>
<td>Deformation</td>
<td>• Deformation survey&lt;br&gt;• Crack/joint meters</td>
<td>• Dam crest&lt;br&gt;• Abutments&lt;br&gt;• Dam blocks</td>
</tr>
</tbody>
</table>

**TABLE A.1. Typical Instrumentation for Concrete Dams**
TABLE A.2. Typical Instrumentation for Embankment Dams

<table>
<thead>
<tr>
<th>Key indicator</th>
<th>Typical instrumentation type</th>
<th>Typical location of instrumentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pore pressure</td>
<td>• Open standpipes</td>
<td>• Dam body</td>
</tr>
<tr>
<td></td>
<td>• Twin tube hydraulic piezometers</td>
<td>• Dam foundation</td>
</tr>
<tr>
<td></td>
<td>• Vibrating wire piezometers</td>
<td>• Abutment</td>
</tr>
<tr>
<td>Seepage</td>
<td>• Weirs or flumes</td>
<td>• Dam downstream toe</td>
</tr>
<tr>
<td></td>
<td>• Turbidity meter</td>
<td>• Abutment toe</td>
</tr>
<tr>
<td>Deformation</td>
<td>• Deformation survey</td>
<td>• Dam crest</td>
</tr>
<tr>
<td></td>
<td>• Surface movements survey</td>
<td>• Abutments</td>
</tr>
<tr>
<td></td>
<td>• Settlement gauges</td>
<td></td>
</tr>
</tbody>
</table>

TABLE A.3. Typical Reading Frequency of Monitoring Instruments

<table>
<thead>
<tr>
<th>Monitoring activity</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine surveillance</td>
<td>Monthly</td>
<td>Weekly</td>
<td>Daily – weekly</td>
</tr>
<tr>
<td>Reservoir level</td>
<td>At routine inspection</td>
<td>Continuous</td>
<td>Continuous/telemetered</td>
</tr>
<tr>
<td>Seepage/leakage</td>
<td>At routine inspection</td>
<td>Monthly – daily</td>
<td>Daily</td>
</tr>
<tr>
<td>Phreatic surface/uplift pressure</td>
<td>Minimum 10-yearly</td>
<td>5-yearly</td>
<td>Yearly</td>
</tr>
<tr>
<td>Deformation survey</td>
<td>Typically not required at site</td>
<td>Daily</td>
<td>Daily – hourly</td>
</tr>
<tr>
<td>Rainfall</td>
<td>As required</td>
<td>Six months – yearly</td>
<td>Monthly</td>
</tr>
</tbody>
</table>

Note: Please adapt the reading frequency of monitoring instruments to the risk classification considered for a project with reference to the section on risk classification in Chapter 7 of the Good Practice Note on Risk-Informed Dam Safety Management.

Installation and Maintenance

Installation, Calibration, and Testing

The installation, calibration, and testing procedure of monitoring instruments should be covered to ensure the instruments are installed correctly for a reliable reading of monitoring data, which is critical for adequate interpretation of the results. Installation of the instruments should be carried out by experienced technicians in accordance with the manufacturer’s manual. Appropriate testing and calibration should be carried out afterward to check whether the instruments are properly operating and sensible data are being obtained. As-built records of the installation, including calibration data, should be kept securely in long-term storage, preferably within and as part of the monitoring system.

Maintenance

A maintenance program should be prepared as part of the IP. It should cover the anticipated frequency of maintenance inspections. Maintenance needs can sometimes be identified during the data evaluation process. A feedback mechanism needs to be in place so those evaluating the data can alert
instrumentation technicians that a maintenance inspection should be carried out. Regular attention to small maintenance needs may prevent the development of larger-scale maintenance activities and ensure the reliability of measurements. Records of maintenance activities should be documented to provide useful information for updating the maintenance plan, maintenance inspection frequency, and secure required resources.

Data Collection, Analyses, and Reporting

Data Collection, Processing, and Storage

Data collection, quality control, and storage procedure should be specified in the design and installation of instrumentation with particular consideration of data collection method (manual or automated data acquisition system), required monitoring frequency and data storage amount, available human and financial resources for data collection, and analyses.

If a larger number of instruments are required, or if the timely delivery of the readings is deemed to be critical to the safety of the dam, it may be appropriate to install a dedicated data-logging system. This will need to be tailor-made with consideration of the number and type of instruments to be monitored.

The instrument data, along with visual surveillance records, should be entered into a tailor-made dam safety monitoring system with appropriate quality assurance measures that protect against unauthorized manipulation. Use of a computer software to record and process the instrumentation data and other surveillance records into desired format for presentation and interpretation should be considered. Although generic spreadsheets may be used for low-risk dams, automated data acquisition system may be considered for medium- and high-risk dams in a suitable manner. In any case, monitoring data should be easily accessible, usable, stored in a safe place, and periodically updated.

Data Analyses and Interpretation

Data analyses and interpretation are fundamental to: (a) understand the dam behavior and performance, (b) detect potential development of defects and deficiencies, and (c) check the performance and maintenance needs of the instrument system.

Data interpretation of instrument records and trends requires skilled engineers. Training is essential to build the capacity of dam owners and operators. Inadequate capacity of data collection and evaluation is a major source of potential risk during the first reservoir filling and long-term operation.

The raw data output by instruments is generally not in suitable units or forms for interpretation and evaluation purposes. The data must be converted using relevant engineering formulae into engineering units more appropriate for interpretation and evaluation purposes. Quality checking should be undertaken to remove anomalous values that may arise from instrumentation issues.

The performance evaluation is carried out by reviewing data outliers and trends against expected overall performance under the prevailing conditions of reservoir water levels and weather conditions (temperature and rainfall) using dam engineering models developed during the design. Presentation of the data to assist in the evaluation process would typically include time plot series, scatter plots.
between two parameters or between instruments with a known relationship, and so on. Data plots would allow the staff to (a) compare actual and predicted behavior of structures, (b) detect data acquisition errors, (c) assess trends and cycle effects of monitoring data, (d) compare various performance indicators of multiple instruments, and (e) predict future behavior of the structure.

It is important to develop the institutional capacity of the dam owner or operator and assign technical staff skilled at interpreting instrument data using databases by providing suitable training programs. Otherwise, outsourcing such technical service should be considered and budgeted. This should be linked to the O&MP.

**Reporting**

Regular reporting to dam safety management should be carried out by dam safety specialists, covering the outcome of the monitoring data analysis and evaluation in terms of the safety condition and performance of the dam and the recommendations for repairs and rehabilitation.

The system should also include the establishment of warning and alarm levels for the items being monitored, beyond which action is immediately taken to review and communicate with managers and dam safety specialists to ensure the continued integrity of the dam.
Annex A: Table of Contents (Sample)

1. Introduction

2. Key Features of Dam
   2.1. Main Characteristics of Dam and Appurtenant Structures
   2.2. Surrounding Conditions and Potential Hazards

3. Instrumentation Monitoring System and Program
   3.1. Purpose of Instrumentation
   3.2. Instrumentation Scope and Requirements
   3.3. Life-Cycle Management of Instrumentation System
   3.4. Monitoring Program (Key Indicators, Instrumentation Types, and Reading Frequency)
   3.5. Installation and Maintenance

4. Data Management
   4.1. Data Collection, Processing, and Storage
   4.2. Data Analyses and Interpretation
   4.3. Reporting

Appendixes
Maps, drawings, diagrams, check sheets, and so on should be attached as appendixes, including the following (examples):

- An inventory of all monitoring instruments (types, numbers, location, key specification, and so on)
- Instrumentation layout plans and as-built drawings
- A table of instruments’ reading frequency
- Manufacturers’ manuals for monitoring instruments