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Instrumentation And Monitoring Of Dams And Reservoirs

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Abstract— **Instrumentation and monitoring of dams and reservoirs as part of dam safety programs provide more absolute and appropriate information with regards to the on-going performance of the dam. 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 of dam. There are many cases of dam failures where early warning signs of failure must have been discovered if a good dam safety-monitoring program had been in place. The use of instrumentation for dam safety concern is increasing as the technology of instrumentation and ease of use advances. For this purpose use of proper instruments is thus very important phenomenon, therefore we must know the various instruments used to find different parameters. The paper presented is oriented to study the instruments essential to successfully implement a dam instrumentation program for dam safety.**

Index Terms— **Assumptions, Dam, Design, Instruments, Monitoring, Planning, Reliability, Safety etc.**

I. 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. While selecting instruments, the following requirements must be taken into considerations-

1. Precision is within the acceptable range;
2. Operation is easy
3. Durability is high, and
4. Repair and replacement are possible.

II. PURPOSE OF INSTRUMENTATION AND MONITORING

After construction of dam, 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.

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2.1.1 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.

2.1.2 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.

III. 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, uplifts pressure, earthquake motion, stress meters, strain gauges and thermometers.
- Embankment dam: leakage, deformation, pore pressure (seepage line), earthquake motion, earth pressure gauges, piezometer, internal displacement gauges.

3.2 Instrumentation Parameters

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

1. Seepage through the dam body and foundations (quality as well as quantity): drainage holes, V-notch weirs.
2. Internal Deformations of the slopes as well as foundations
   a. Deformation (concrete dam): plumb lines, external targets.
   b. Deformation (embankment dam): differential settlement gauges, external targets.
3. Uplift pressure: Borden tubes, piezometers, Pore pressure: piezometers.
4. Earthquake motion: strong motion seismographs.

5. Surface settlements: Along the dam length and ledges or berms.
6. Reservoir and tail water levels: Different type of gauges differential- transformer-type, and vibrating-wire-type.

IV. TYPES OF MEASUREMENTS

There are various types of measurements for determining the performance as per aforesaid parameters. Details of some them are as follows:-

4.1 PORE PRESSURE

The measurement of pore water pressure takes a very important role , which enables to know the seepage pattern set up after impounding of reservoir and also valuable information about behaviour of dam during construction and draw-down condition is obtained. Under an externally applied stress, soil grains are constrained into more intimate contact and the soil mass volume decreases. Because soil grain volume cannot be changed appreciably, this volume change must take place primarily in the soil voids or pores. In the event if these pores are fully filled with water, their volume cannot be altered unless some water is depleted from the soil mass, because water is considered incompressible. If drainage is prevented or impeded, stress will create in the pore water (i.e. pore water pressure) counter reacting the externally applied stress. Pore water pressures are a controlling factor on stability during construction.

4.2 MOVEMENTS/ DEFORMATION

Measurement of movements is as imperative as the measurement of pore pressures. Movements conforming to normal expectations are essentially pre-requisites of a stable dam. An exact measurement of internal and external movements is of esteem in controlling construction stability. The measurement of the plastic deformation of the upstream and downstream slopes under the cycles of reservoir operation may indicate the likely development of shear failure at weak points.

4.3 SEEPAGE

Ceaseless movement of water through the soil of a structure may result in removal of soluble solids or may

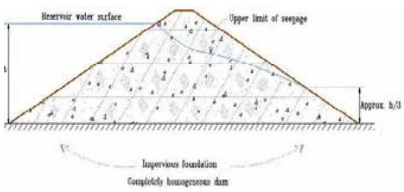

Fig. 1: Seepage flow through earth dam with no filter at the dam toe

result in internal erosion called channeling. Channeling must especially be protected against since it happens gradually and is often not frequent until the structure's failure is imminent. Seepage and erosion along the lines of destitute compaction and through cracks in foundations and fills may extraordinarily be shown by such measurements.

4.4 STRAINS AND STRESSES

Design analysis of earth and rockfill dams are based on radical simplifications of the stress pattern and the shape of the rupture planes. Stress measurements, in this manner, require significant judgment in interpretation. Accurate measurement of stress is troublesome and distribution of stress in earth and rockfill dams is complex. Strains may be calculated from displacements or measured straightforwardly.

4.5 DYNAMIC LOADS (EARTHQUAKES)

The investigation of the behavior of dams hit by seismic tremors in past, clearly appears that these structures have high inherent capability to resist the seismic forces, provided they are well designed and built. IN nay case there are evidences too that outstandingly strong seismic tremors have produced remarkable damages, in this way showing that the real seismic behavior of these structures is not yet fully understood, and subsequently a few advancement their design is still possible. These contemplations support and legitimize the concept that it is prudent to introduce on these structures seismic surveillance system. Seismic tremor causes sudden dynamic loading and measurement of vibrations in dams located in areas subjected to seismicity are important for advancing design criteria for such conditions.

4.6 MEASUREM*ENTS OF RESERVOIR AND TAIL WATER LEVEL*

Reservoir and tail water heads being one of the vital loading to which a dam is subjected, the measurement of reservoir and tail water levels is basic for interpretation and reasonable appraisal of the structural behaviour of the dam.

4.7 WAVE HEIGHT

Records of wave height data in conjunction with wind velocity and other relevant data assist in choosing free board requirements more reasonably.

4.8 *Rainfall*

This measurement is vital for interpretation of pore water pressure and seepage advancement in earth dams.

V. PLANNING FOR GEOTECHNICAL INSTRUMENTATION

An accurate determination of the wide variety, type, and vicinity of instruments required at a dam can best be addressed effectively through combining enjoy, experience, common feel, and intuition. Dam/ hydro projects represent precise situations and require individual solutions to their instrumentation requirements. Therefore planning of an instrumentation machine have to be such that the specified facts can be acquired both at some point of construction in addition to at some point of the life of the venture.

5.1 Selection of Instruments

5.1.1Reliability

Reliability is the most suited feature in the selection of monitoring instruments. This is to ensure that reliable facts of adequate accuracy can be obtained throughout the period when the records is needed. Often there is a tendency for looking unnecessarily high accuracy and when accuracy and reliability are in conflict, excessive accuracy need to be sacrificed for excessive reliability. Excessive accuracy frequently calls for immoderate delicacy and fragility. Commonly the most reliable instrumentation devices are the handiest devices. Where a desire exists, the less complicated device is probable to have more fulfilment. The performance file of commercially available instruments must be taken into consideration.

5.1.2 Locations

Locations for instruments need to be determined based on predicted behavior of the site. The locations have to be compatible with the geotechnical issues and the method of analysis a way to be used when decoding the data. Figure No 2 represents typical instrumentation layout showing instruments for existing dam. A practical technique for selecting instrument locations includes following:

(i) Pick out zones of particular concern such as structurally weak areas that are most heavily loaded, and locate suitable instrumentation,

(ii) Choose zones that can be represented by typical cross sections where expected behavior is considered representative of behavior as a whole,

(iii) Pick out zones where there is discontinuity inside the foundation or abutments,

(iv) Install some extra instruments at other potentially critical secondary locations to function as indices of comparable behavior, and

Locate rows of survey monuments at periods in the longitudinal direction at suitable elevations.

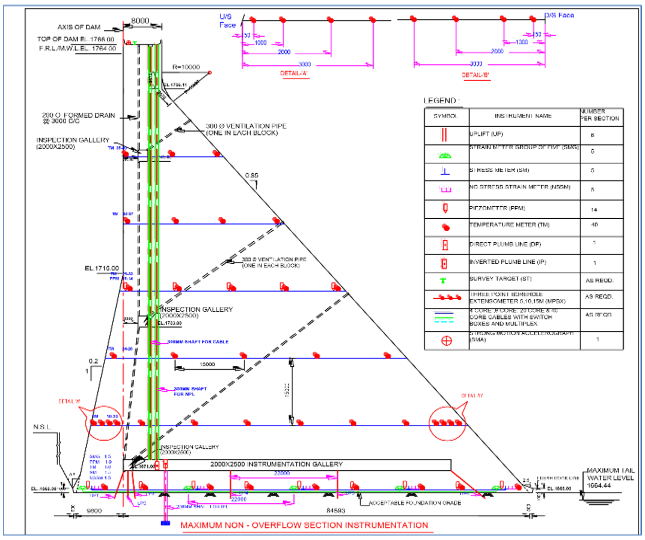

Figure No. 2. Typical instrumentation layout showing instruments for existing dam

(Source: DRIP 2018 Publications[2])

Table 1: Typical instrumentation used in evaluating causes of common problems/concerns

Problem/concern	Typical instrumentation
Seepage or leakage	Visual observation, weirs, flowmeters, flumes, calibrated containers, observation wells, piezometers
Boils or piping	Visual observation, piezometers, weirs
Uplift pressure, pore pressure, or phreatic surface	Visual observation, observation wells, piezometers
Drain function or adequacy	Visual observation, pressure and flow measurements, piezometers
Erosion, scour, or sedimentation	Visual observation, sounding, underwater inspection, photogrammetric survey
Dissolution of foundation strata	Water quality tests
Total or surface movement (translation, rotation)	Visual observation, precise position and level surveys, plumb measurements, tiltmeters
Internal movement or deformation in embankments	Settlement plates, cross-arm devices, fluid leveling devices, pneumatic settlement sensors, vibrating wire settlement sensor, mechanical and electrical sounding devices, inclinometers, extensometers, shear strips
Internal movement or deformation in concrete structures	Plumb lines, tiltmeters, inclinometers, extensometers, joint meters, calibrated tapes
Foundation or abutment movement	Visual observation, precise surveys, inclinometers, extensometers, piezometers
Poor quality rock foundation or abutment	Visual observation, pressure and flow measurements, piezometers, precise surveys, extensometers, inclinometers
Slope stability	Visual observation, precise surveys, inclinometers, extensometers, observation wells, piezometers, shear strips
Joint or crack movement	Crack meters, reference points, plaster or grout patches
Stresses or strains	Earth pressure cells, stress meters, strain meters, over coring
Seismic loading	Accelerographs
Relaxation of post-tension anchors	Jacking tests, load cells, extensometers, fiber-optic cables
Concrete deterioration	Visual observation, loss of section survey, laboratory and petrographic analyses
Concrete growth	Visual observation, precise position and level surveys, plumb measurements, tiltmeters, plumb lines, inclinometers, extensometers, joint meters, calibrated tapes, petrographic analyses
Steel deterioration	Visual observation, sonic thickness measurements, test coupons

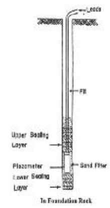

Fig. 3: Vibrating Wire Piezometer Installation

The vibrating wire Piezometer contains a steel wire extended between a fixed anchorage and a sensitive stainless steel diaphragm. The ends of the wire are anchored to ensure excellent long-term stability. An electromagnetic coil assembly, located close to the wire, is utilized to pluck the wire and also to sense and convert the subsequent wire vibrations into an electrical AC output whose frequency is related to the tension of the wire. Change in pore water pressure cause the diaphragm to deflect, thus altering the tension of the wire and consequently the frequency of the output (pore pressure is proportional to frequency). This frequency is measured using an advanced Digital Readout Unit and readings can be displayed in units of pressure. Since only frequency is measured, changes in the length, resistance or temperature of the connecting cable have a negligible effect on the signal (as assumed). Transducers are fabricated completely in stainless steel mounted in a rigid PVC housing.

i) BORE HOLE EXTENSOMETER

Bore Hole Extensometer is an instrument for measuring deformation and measures longitudinal displacement between two points in fill and lateral strains in earth dams. It has an external pipe fitted with two end flanges and an internal stainless steel rod. One end of the rod is joined to a flange, while the other end of the rod is joined to a displacement sensor, which is attached to the other flange.

The Bore Hole extensometer (typical image shown in Fig.4) is designed for short term or long term observations of displacements between two points inside any type of manmade fill. The base length, the distance between the two end flanges, is variable and is generally from 1.5 to 50 meters. The fill extensometer is normally installed horizontally in trenches and can be assembled in series using threaded rods inserted in the holes on each end flange. However, in some applications such as for measuring settlement at the point of contact with the foundation, it is installed vertically. Reading are obtained with a portable FC Series readout or with a C.A.F. or SENS– LOG automated data acquisition system. Each instrument comes with a calibration curve to convert frequency into a displacement value.

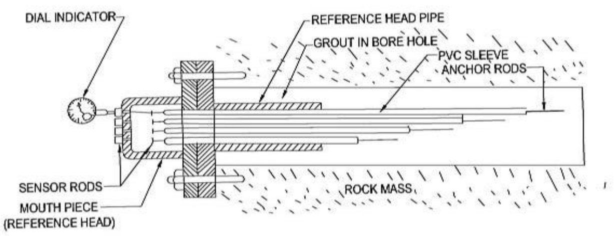

Fig. 4: Bore Hole Extensometer

ii) JOINT METER/CRACK METER

Joint meter is typically to measure relative movement across joints and consists of a displacement transducer, fixed between anchors on opposite side of the joints. 3D crack meters are utilised to monitor three way displacement (X, Y and Z) across joints or cracks between adjoining concrete and rock structures.

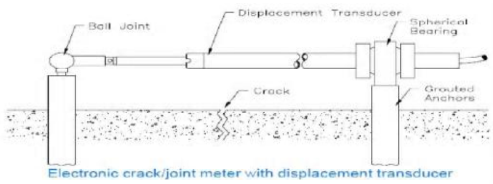

Fig. 5: Electronic Joint Meter with displacement transducer

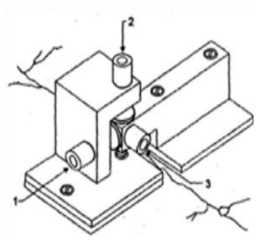

Fig 6 : 3D- Crack Meter

Fig 7: Joint Meter

iii) OPEN CHAMBER PIEZOMETER (OCP)/ POROUS CHAMBER PIEZOMETER (PTP)

This piezometer (Fig 8) is utilized to measure water Pressure in Spillway / Dam body. The porous tube is set in gap drilled into the foundation to a pre-defined depth to measure pore water pressure in the foundation. The pressure of the pore water surrounding the porous tube causes a flow through the piezometer until in the pressure is equalized by the head of water in the standpipe (plastic tube). The rise of water within the plastic tube is determined by Water Level Sounder. Its run may vary from 0 to 15 m.

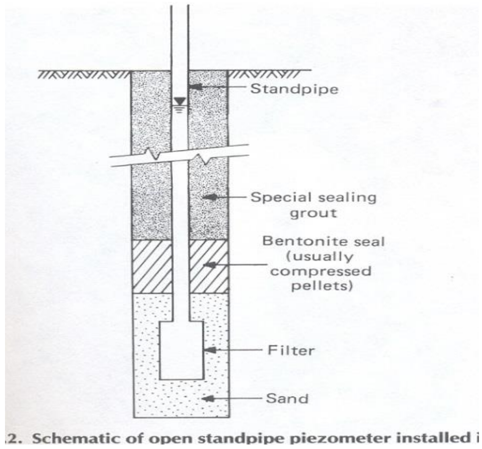

Fig. 8: Open Chamber Piezometer

iv) **Total Stress Measurement**

Total stress measurements in soil fall into two fundamental categories: measurements inside a soil mass (with embedment earth pressure cells) and measurements at the interface (with contact earth pressure cells).

A. viii) Seepage Measurement

Seepage measuring gadgets are utilized in dams to measure amounts of seepage through, around, and beneath the dam body. Perceptions of seepage rate can be connected with measurements of piezometric pressure, and be used to look the viability of drains, relief wells, and cutoffs.

v) **Seismic Measurement**

The obsolete concept that seismic instrumentation of earth and rockfill dams and reservoir sites are only an investigating tool has given way to the advanced concept that seismic instrumentation is necessary for moderate-to-high risk dams in seismic ranges. Three types of recording gadgets are popular today. They are:

i) Acclerograph,

ii) Seismic acceleration alarm device (SAD), and

iii) Non-electronic peak Acclerograph recorder.

VI. RISING TREND IN INSTRUMENTATION

A rising trend in instrumentation is Distributed Fiber Optical innovation. This optical innovation recognizes and measures seepage flow all along the complete dam. This can be used in brief and long term checking of seepage flow variations. In this temperature measurement is used to identify the seepage. This is being widely used in Sweden and Germany e.g. Hylte Dam, Sweden. This technology uses scattering characteristics of laser light where scattered light has strong relation to temperature and detector measures the change in power and frequency of scattered light against time at all positions of fiber. Seasonal temperature changes are also measured and strongly related to seepage flow.

VII. Conclusion

Instrumentation, which is essentially a technology of measurements, helps in monitoring and evaluating the performance of dams during their construction as well as during their operation. It facilitates in locating distress areas and providing remedial measures. Instrumentation greatly helps in checking the theories used in design and validating them. Such a comparison between prediction and performance become invaluable for indicating the directions in which design principles can be improved and erroneous concepts discarded. The behaviour of dam during construction and operation is being and shall be monitored through well planned scheme of instrumentation. Various instruments are typically required in the construction of large, highly hazardous dams, and may be necessary on existing dam rehabilitation projects. Instruments can be installed to monitor the performance of the dam during construction, during initial reservoir filling, and during the life of the structure. Other less common instrumentation may be considered for unusual conditions. Any instrumentation selected should target specific items to be evaluated, establish critical thresholds that suggest the need for a specific action, and establish the details of the monitoring programs.

Foundation and embankment performance may be monitored with piezometers, settlement devices, inclinometers, and seepage measuring devices, displacements may be measured with tilt meters, seepage can be monitored and calculated using V- notch weirs, strain may be measured by using strain gauges, stress in the dam body may be monitored by installing total pressure cells, dynamic loads can be monitored using seismometers, temperatures can be monitored by using temperature sensors.

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