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Instrumentation of Earth & Rock Fill Dams

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***Abstract*— An effective instrumentation and monitoring program combined with regular inspection are the key factors of a good dam safety program. Instrumentation data can be of benefit only if the instruments function reliably, the data are received and evaluated in a timely manner and values are compared to the documented design limits and historical behavior.**

***Index Terms*— seepage, deformation, frequency, instrumentation, pore pressures etc**

I. INTRODUCTION

Many effects can result from the failure of a dam, the worst of which is the loss of life which is highly influenced by three factors:
-The number of people occupying the dam failure flood plain,
-Timeliness of dam failure warnings, and
-The severity of flooding.
Historically, dam failures that have caused high fatality rates were those in which timely dam failure warnings were not issued, resulting to severe consequences. Instruments are used for monitoring performance of dams, which involve measurement of settlement, seepage, deformation, total stress and pore pressures within the structure and its foundation. Such type of instrumentation is essential to gather information on the performance of the behaviour of the dam during construction, first filling of the reservoir and during long term service operation. The amount and kind of instrumentation used and the frequency of measurements are important parameters.

II. INSTRUMENTATION PHILOSOPHY

Instrumentation may be used to assist in evaluating cause of the unexpected behaviour of dam, in which instruments are the tools, which helps to monitor the health and life of the hydraulic structures. ldeally, instruments used in a given situation should have the following characteristics:
-Sufficient accuracy
-Long-term reliability
-Low maintenance requirements
-Compatibility with construction techniques
-Low cost, and

III. NEED FOR INSTRUMENTATION

Instrumentation is used for following purposes:
-Initial site investigations - soil permeability, pore-water pressure and slope stability
-Checking design assumptions
-Quality control
-Performance, and
-Safety

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IV. REQUIREMENT OF INSTRUMENTATION

The list of the type of parameters to be monitored for embankment dams is:
-Pore water pressures
-Internal movement
-External movement
-Settlement at different levels
-Seepage (total and from different parts) and
-Horizontal deformations

Table1

S. No.	Parameters	Instruments
1	Pore-water pressure within the embankment	Standpipe, Pneumatic and Vibrating wire piezometers.
2	Total stress at contact points between embankment and any structures	Vibrating wire pressure Cells.
3	Leakage downstream	V-notch weir monitors
4	Vertical deformation within the embankment	Double fluid settlement Gauges, Horizontal inclinometers, Magnetic probe extensometers.
5	Lateral deformation within the embankment	Magnetic probe extensometers, Vibrating wire soil extensometers, Inclinometers.

The measurements of the parameters at the following stages are important:

Measurements during construction and first filling: The primary purpose of these measurements is immediate safety. Moreover, during first filling it can provide a starting point for evaluating the importance and severity of any variations in the behaviour of the dam and its foundation.

Measurements during Operation: It provides useful information on the behaviour of the structure both as a whole and at some particular points. The main purpose is to offer a reliable picture of all evolutions favourable or grounds for concern.

V. SELCTION OF INSTRUMENTS

There is no simple rule which can determine the number of instruments, their exact type or location. Their determination remaining primarily a matter of experienced judgment. The number of devices installed in a dam is less important than the selection of proper types of instruments, their location and intelligent interpretation of the data. The quality of instruments should be of paramount importance since these are expected to work for very long periods, say 25-30 years. More importantly so because embedded instruments cannot be retrieved and repaired if these become defective. In a selection of equipment, service requirements must be carefully weighed. An instrument of rugged construction that gives reasonably accurate results may be preferable to a more precise but delicate instruments.

Engineers should be very careful while selecting instruments. Most important criterion should be reliability and cost effectiveness. Also it should be suitable for the purpose to be used for, easily operational, comparable portability. Successful field measurements can only be possible if instruments are simple, reliable and adequate. The following minimum requirements should also be ensured in addition to the above:

-Range
-Sensitivity/resolution
-Repeatability
-Accuracy

VI. TYPE OF INSTRUMENTS

A. Piezometer

A piezometer is a device sealed within the ground to measure water pressure in its immediate area. The measurement of pore water pressure is very important, 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.

Fig. 1: Stand-Pipe Piezometer[1]

The pore pressure near the upstream side before the filter should be almost equal to the water level of the reservoir at that point. The pore pressure drops along the filter in the middle of the dam and should be approximately zero near the downstream side. Piezometers can be of the stand-pipe, pneumatic or vibrating wire type. Table2 gives the advantages and disadvantages of these types:

The vibrating wire piezometer works on the principle of measuring the change in frequency of vibrating wire with the change in pore pressure and are particularly suitable for installation in impervious and highly plastic clayey material (fig. 2).

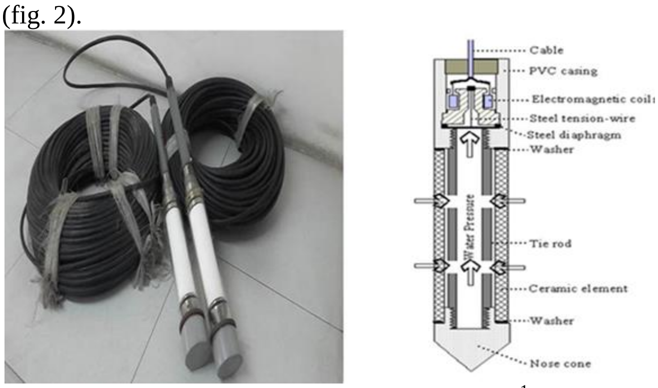

Fig. 2: Vibrating Wire Piezometer[1]

The pneumatic piezometers are hydraulically activated system of water filled tubes which connect piezometer tips located in embankment or foundation to a terminal house. The pore pressure is transmitted through these tubes to Bourden Gauges. There are two types of tips used in these instruments; foundation type and embankment type (fig. 3).

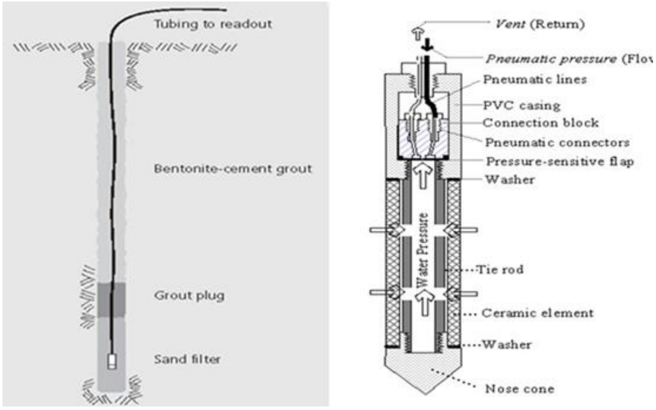

Fig. 3: Pneumatic Piezometer

Table.2[1]

Type of Piezometers	Advantages	Disadvantages
Standpipe	Reliable. Long successful performance record. Self-de-airing if adequate standpipe diameter.	Long-time leg for final reading. Easily damaged by construction, traffic and equipment. Filter can become plugged.
Pneumatic	Short time leg to final reading. Calibrated part of system is accessible. Minimum interference to construction.	Very sensitive to leaks, gas flow rate and length of tubing.
Vibrating	Easy to read. Short time leg to final reading. Minimum interference to construction. Can read negative pore water pressures.	May need lightning protection. Manufacture needs to be of high quality to minimise zero drift.

B. Earth pressure cell:

These instruments are used to measure pressure and stress distribution within embankments in long term. The pressure cells should be located in the maximum stress locations such as near the foundation and where the height of the dam is maximum. A pore pressure meter should be located near the earth pressure cell to know the value of true stress.

In vibrating wire type of cell, the gauge wire is stretched between two protruding arms fixed at the bottom of the circular diaphragm, as shown in figure 4. An increase in pressure on the diaphragm will rotate the protruding arms thereby causing a change in the tension in the wire and consequently the frequency of the wire. These changes can be noted through a frequency meter and calibrated against the earth pressure acting on the diaphragm. Schematic diagram is as shown in fig. 4.

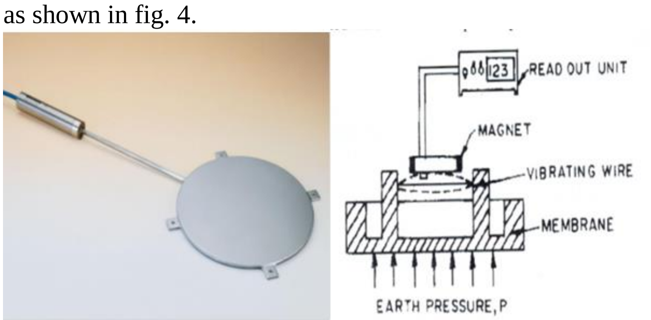

Fig. 4: Schematic view of Vibrating Wire Earth Pressure Cell[4]

C. Inclinometers:

These are used for monitoring deformation normal to the axis of a pipe, by means of a probe passing along the pipe. The pipe can be horizontal, vertical or inclined and will have four grooves along its length to act as a guide for the inclinometer probe wheels as shown in fig. 5.

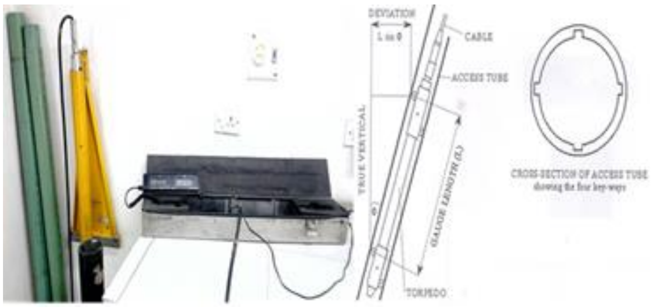

Fig. 5: Inclinometer probe with casing[1]

D. Magnetic probe type Horizontal Movement device:

This device is used for monitoring horizontal movement on the downstream of the dam. Telescopic access tubes are laid at the base of a trench with plate magnets positioned outside in the surrounding soil at proposed locations. A probe incorporating a Reed switch is made to travel within the tube to sense the position of magnets outside giving a buzzer signal. The corresponding reading on the tape indicates the present position. The installation of *Horizontal Movement Device* is shown in fig. 6.

Fig. 6: Horizontal Movement Gauge

E. V-Notch Weir

The device used for measuring seepage discharge, comprises of liquid level float, vibrating wire transmitter and an indicator. Liquid level indicator consists of V-notch weir and a sensing element comprising of a cylinder suspended from vibrating wire transducer assembly. A pair of vibrating wire strain gauges is provided with vibrating wire transducer to measure the difference in weight of cylinder at various degree of submergence. The device shall be installed at the toe of the dam at the desired location as shown in fig. 7.

Fig. 7: V-Notch Weir

F. VW Temperature Sensor

These instruments are used to measures the temperature gradient and change in thermal condition of foundation after filling of reservoir. The concentrated seepage through the cracks, fissures and shear zones present are also detected with the help of these instruments. Typical temperature sensor is shown in fig.8.

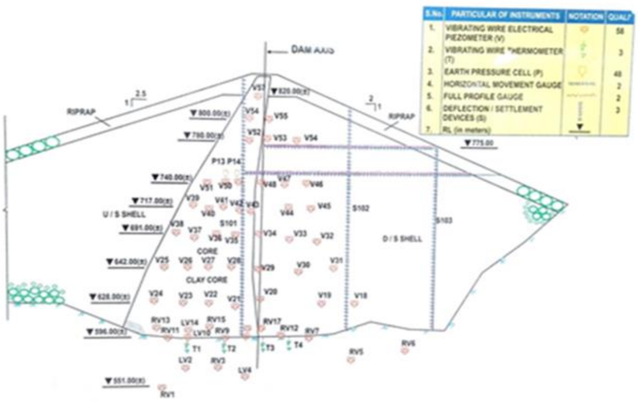

Fig. 8: Temperature Sensor

VII. CASE HISTORY

The scheme of instrumentation adopted for Tehri Dam provides for monitoring of the following parameters[4]:

-Pore pressure with-in the structure and its foundation.
-Structural displacements, deformations and settlements in the body of the dam.
-Vertical and horizontal displacements at the surface of dam
-Seepage.

The instruments are mainly provided in three sections; on near the deepest section (B-11) and one on either side of the deepest section at a distance of 120 m from the deepest section (B-7 and B-15). Instruments have also been provided near to the top of embankment along the dam axis to monitor horizontal displacement and formation of transverse cracks in tension zones.

Fig. 9 Instrumentation of Tehri Dam[1]

VIII. Conclusion

An effective instrumentation and monitoring program combined with regular inspection are the key factors of a good dam safety program. It should be understood that the instruments themselves can be the cause of problems, if compaction has been imperfect due to the presence of vertical pipes, tubes or cables during filling.

Instrumentation data can be of benefit only if the instruments consistently function reliably, the data values are compared to the documented design limits and historical behavior, and the data are received and evaluated in a timely manner.

References

[1] Monograph (2012), Geotechnical Instrumentation, CSMRS (p.g.14).
[2] Dunnicliff, J. (1988, 1993). Geotechnical Instrumentation for Monitoring Field Performance, John Wiley & Sons, Inc., New York.
[3] ASCE Task Committee" Guidelines for Instrumentation and Measurements for Monitoring Dam Performance." (pgs., 3-18 and 11-26).
[4] G.N. Mathur, Dr. A.S. Chawla, E. Sundaraiya, CBIP Publication no. 287, "Instrumentation of Dams", (pg.53, 308).U.S. Bureau of Reclamation (1974)

FREQUENCY OF READINGS

	Progress Report During Construction		Periodic Report Operation	
	Frequency of Readings		Frequency of Readings	
	Construction	Shutdown	First Year	Regular
Piezometer readings (separate gages)	Twice monthly	Monthly	Monthly	Monthly
Piezometer readings (master gage)	Monthly	Alternate months	Approximately 6 months after completion of dam	Annually on same date as a set of separate gage reading
Porous tube piezometer readings	Twice monthly	Monthly	Monthly	Monthly
Internal vertical and horizontal movement readings (cross arm or HMD)	Complete set of readings each time a unit is installed	Monthly	Complete set approximately 6 months after dam is completed	Every 2 years
Foundation Settlement readings (baseplates)	Complete set of readings each time an extension is added	Monthly	Approximately 6 months after dam is completed	Every 2 years
Measurement points-cumulative settlement and deflection readings	Monthly, if required, or when dam is completed	Monthly, if required	Approximately 6 months after dam is completed	Every 2 years
Measurement points-cumulative settlement and deflection readings spillway and outlet works	Monthly as portions of structures are completed	Monthly	Approximately 6 months after structure is completed	Every 2 years
Measurement points-cumulative settlement and deflection readings spillway floor slabs	Monthly as slabs on structure are completed	Monthly, if required	Approximately 6 months after structure is completed	Every 2 years

Source: U.S. Bureau of Reclamation (1974)[5]