MONITORING AND SURVEILLANCE OF EMBANKMENT DAMS

DAM INSTRUMENTATION

Monitoring

The **observing of measuring devices** that provide data from which can be deduced the performance and behavioral trends of a dam and appurtenant structures, and the **recording of such data**.

Surveillance

The continuing examination of the condition of a dam and its appurtenant structures and the review of operation, maintenance and monitoring procedures and results in order to determine whether a hazardous trend is developing or appears likely to develop.

Instrumentation of a dam furnishes data to determine if the completed structure is functioning as intended and to provide a continuing surveillance of the structure to warn of any developments which endanger its safety (ICOLD, 1969) .

REASONS FOR INSTRUMENTATION

➢ Warning of a Problem

Instruments can detect unusual changes, such as water fluctuations in pressure that are not visible (e.g. development of a serious seepage problem) .

➢ Analyzing and Defining a Problem

Instrumentation data is frequently used to provide engineering information necessary for analyzing and defining the extent of a problem

➢ Proving behavior is as expected

Instruments installed at a dam may infrequently (or even never) show any anomaly or problem (shows that the dam is performing as designed and provides peace of mind to an owner).

- ➢ Characterize site conditions before construction
- ➢ Evaluate behavior during construction, first filling, and operation of the structure
- ➢ Evaluate performance of specific design features
- ➢ Observe performance of known geological and structural anomalies; and
- ➢ Evaluate performance with respect to potential site-specific failure modes

Monitoring Parameters

Various parameters to be monitored for safety of any dam include the following

a) **Physical condition** – slopes, surfaces, reservoir rim, sand boils in the dam toe area

b) **Discharges** – inflows, outflows, spillway flow

c) **Seepage flow** – pressure relief wells, toe drain, drainage gallery under spillway, abutments

d) **Water level** – Reservoir and tail water levels, wave amplitude and frequency

e) **Movements** – crest settlement, deflection, lateral movement, dam interior settlement/ deflection, abutment movement/ deflection

f) **Pore water pressure** – at various locations in the dam core, shell, foundations, uplift pressure under structures, etc.

g) **Movement of joints, cracks**

h) **Point loads, stress, strains** – in the concrete dam and various structures and

i) **Temperature** – in the dam body and exteriors, in shafts, passage ways, reservoir water temperatures

Monitoring Parameters (continued)

j) **Water quality** – depth wise quality of reservoir water, seepage water (for suspended and dissolved substances) and chemical contents

k) **Meteorological / weather parameters** – max-min temperatures, wind velocity/direction , rainfall, ice, relative humidity, pan evaporation rate, solar radiation

l) **Seismic activity** – earthquake, ground acceleration

INSTRUMENT TYPES AND USAGE

Visual observations

- visual observations by the dam owner or the owner's representative may be the most important and effective means of monitoring the performance of a dam
- Consists of a minimum of walking along the dam alignment and looking for any signs of distress or unusual conditions at the dam

Movements (Deformations)

Movements occur in every dam. They are caused by

- stresses induced by reservoir water pressure
- unstable slopes (low shearing strength)
- low foundation shearing strength
- settlement (compressibility of foundation and dam materials),
- thrust due to arching abutments or foundation

Horizontal Movement

It involves the movement of an entire dam mass relative to its abutments or foundation Dam crest and deeper layers can move. In an embankment dam, instruments commonly used for monitoring such movement include:

- Extensometers
- Multi-point extensometers
- Inclinometers
- Embankment measuring points, etc.

Vertical Movement

A result of consolidation of embankment foundation materials resulting in settlement of the dam

In an embankment dam, vertical movements may be monitored by

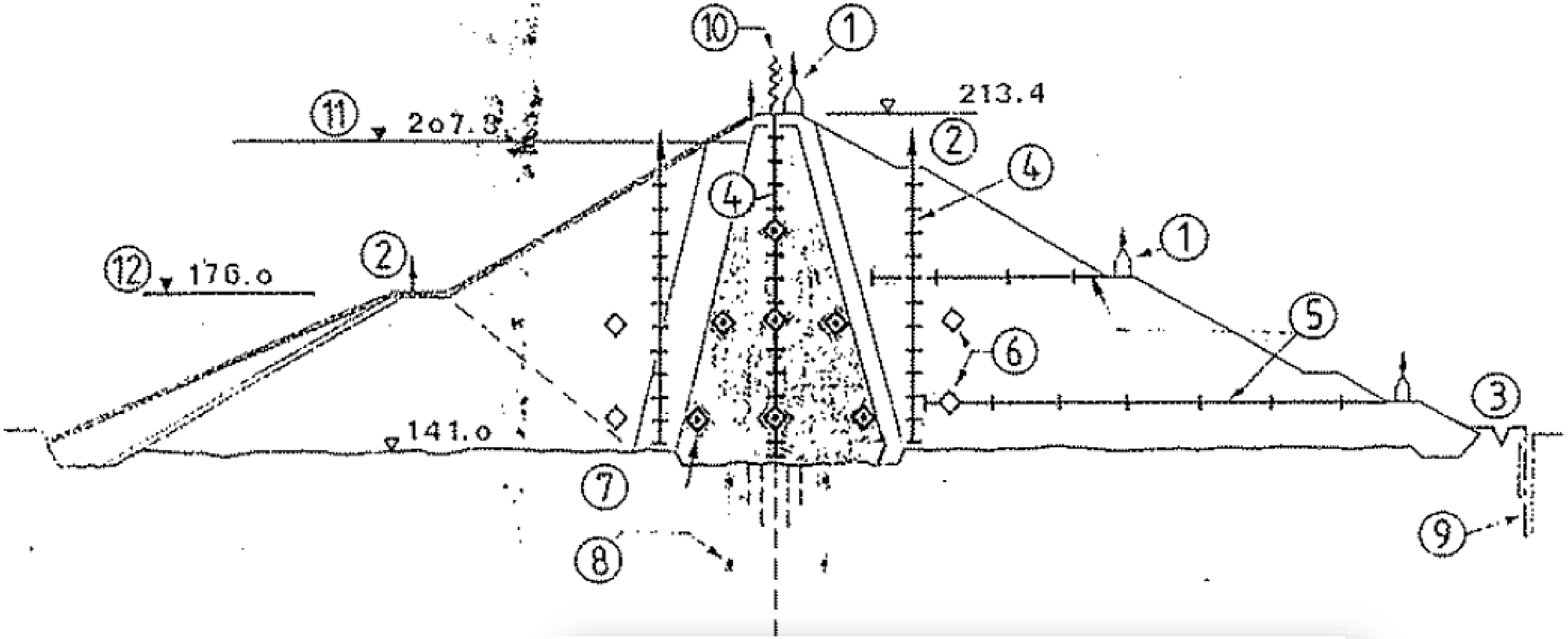
- surface reference markers/monuments
- Settlement plates/sensors
- Extensometers

Rotational Movement/deflection

This kind of movement may be measured in either embankment or concrete dams by instruments such as:

- Extensometers
- Inclinometers

Typical instrumentation of a rockfill dam with earth core

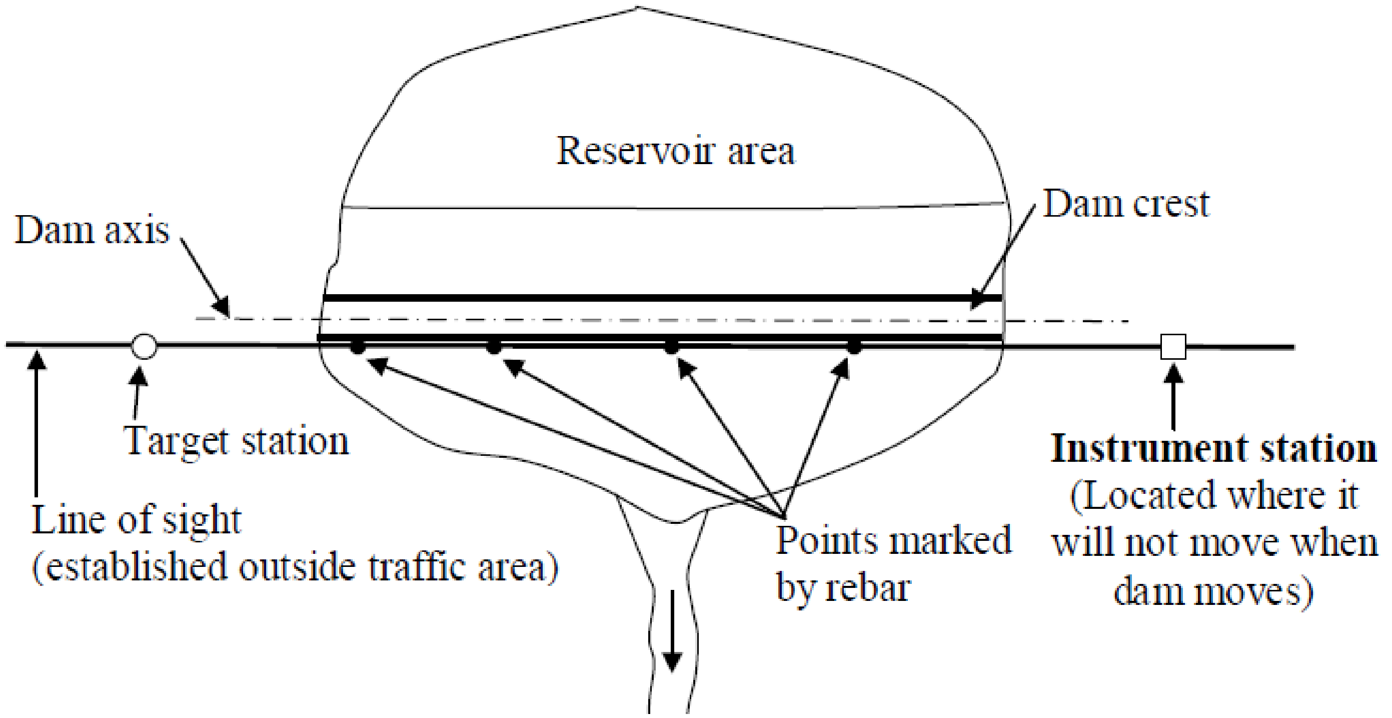


1 Surface survey point and measuring chamber
2 Surface survey point
3 Measuring weir for seepage control
4 Settlement gauges
5 Horizontal displacement gauges
6 Earth pressure cells
7 Pore-water pressure and earth pressure cells
8 Borehole piezometer for joint-water pressure
9 Ground water observation hole
10 Seismograph
11 Full supply level
12 Min. operating water level

Survey reference markers/ Survey points

- Survey reference markers are installed at dam crest in a straight alignment, and tied to two permanent markers installed on the right and left abutments

- Periodic survey for alignment control and elevation of the markers will provide information about crest deflection and settlement.

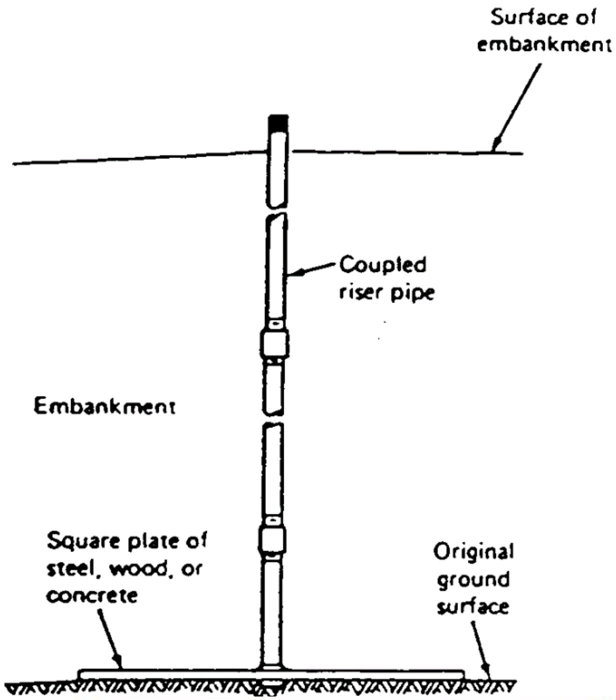


benchmark

Settlement plates/sensors

Buried plate

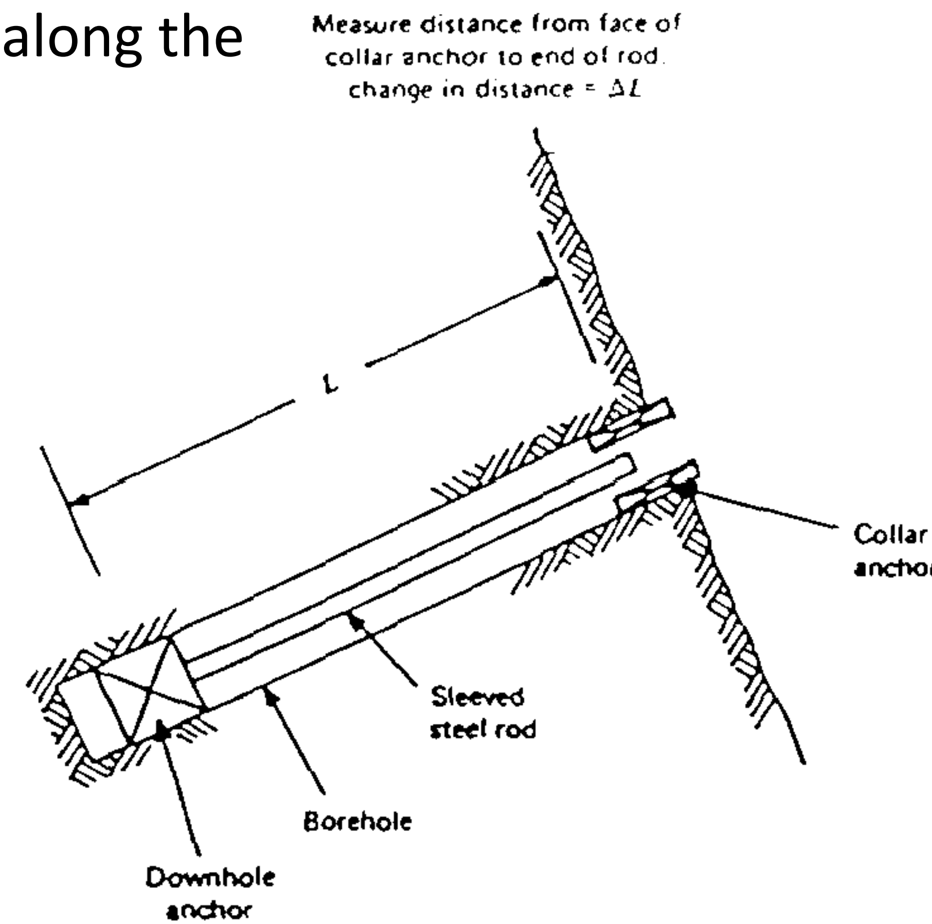
To take an elevation reading on the plate, a vertical borehole is drilled, jetted, or augered from an accurately surveyed surface position, the plate located, and a depth measurement made. An accurate record must of course be made of the initial location of the plate in plan and elevation, and the plate must be large and level.



Extensometers

Fixed borehole extensometers

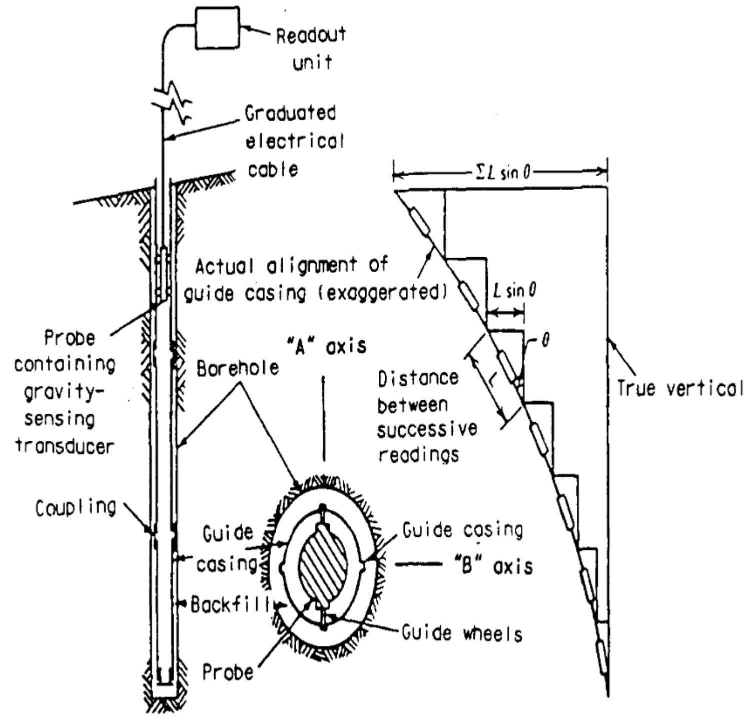
- Installed in boreholes in soil or rock for monitoring the changing distance between two or more points along the axis of a borehole



Inclinometers

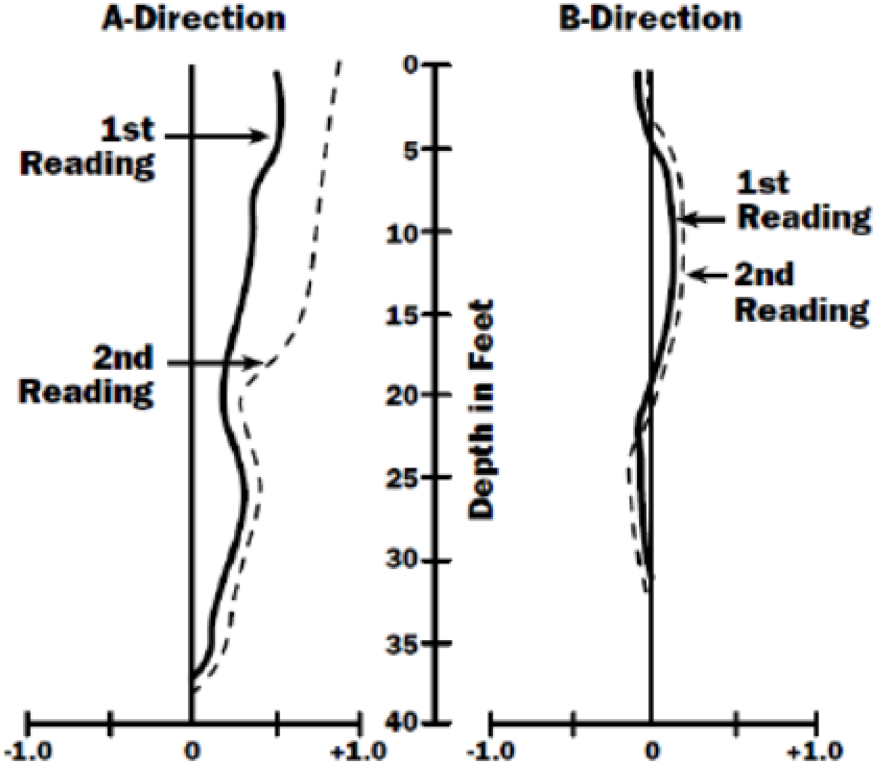
Inclinometers are defined as devices for monitoring **lateral movement** by means of a probe passing along the pipe.

- Monitor lateral earth movements in embankment e.g. detect movement of D/S of earth fill dam, particularly during impounding.
- Determine shear and zone in foundation.
- Monitor stability of U/S slope during and after impounding.
- Determine depth, direction, magnitude and rate of movement

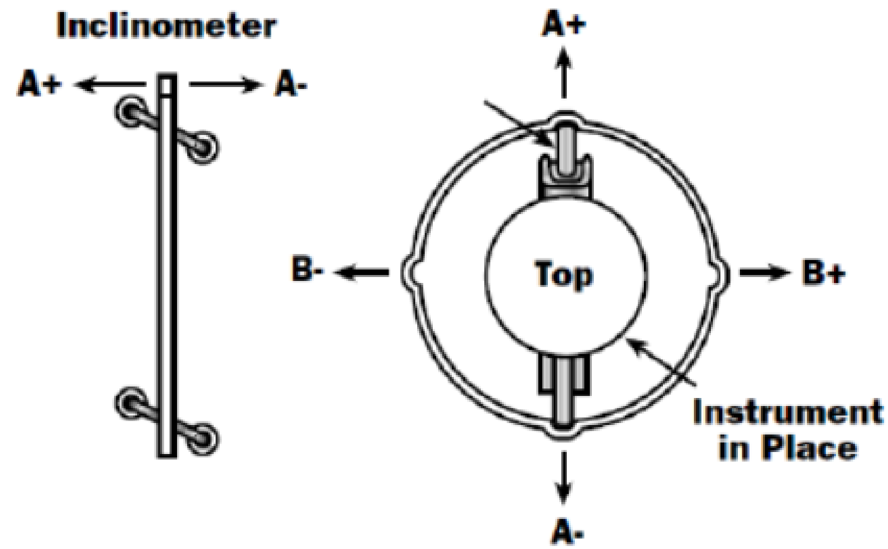


The pipe may be installed either in a borehole or in fill, and in most applications is installed in a near-vertical alignment, so that the inclinometer provides data for defining subsurface horizontal deformation.

Plot of Inclinometer Readings

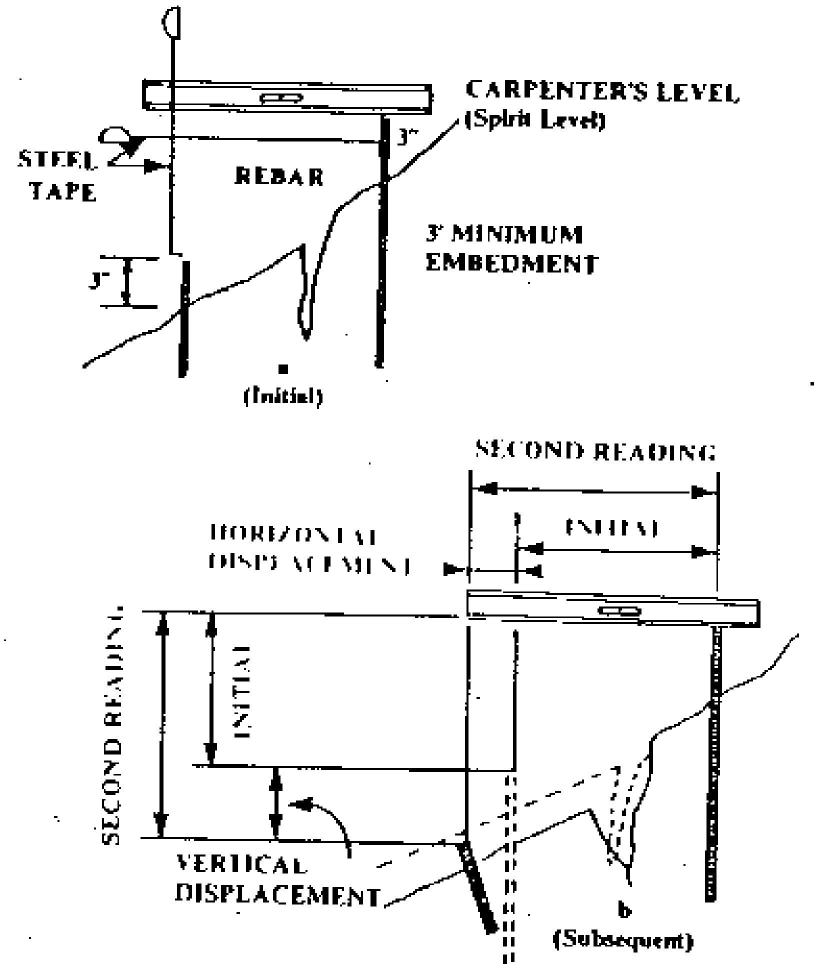


Inclinometer and Casing



Crack and Joint Size

- The locations and widths of cracks and joints is important because of the potential for seepage through those openings.
- Know if the width of such openings is increasing or decreasing.
- Various crack and joint measuring devices are available (Some use simple tape or dial gauges, while others use complex electronics to gain measurements).



Monitoring cracks on embankments

Reservoir Water Level

This measurement helps in meeting three objectives:

- Improving reservoir management through continuous knowledge of the volumes of water that are available;
- Participating in dam monitoring by allowing examination of the influence of reservoir water level on measurements taken by certain instruments (in particular flows and uplift pressures);
- Enriching hydrological data trough measurement of flood flows

Staff gages are the simplest method for measuring reservoir and tail water levels. Staff gages are reliable and durable.

Groundwater Level and Pore Water Pressure

- Pore pressures can be monitored with Piezometers

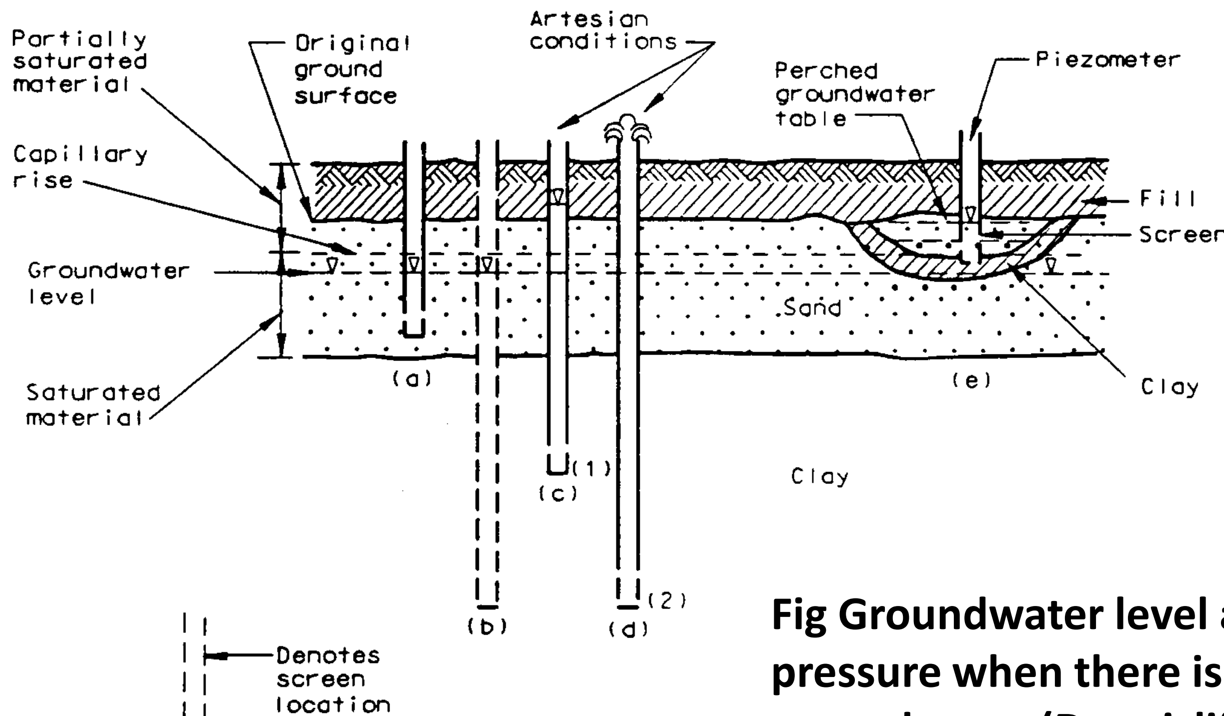


Fig Groundwater level and pore water pressure when there is flow of groundwater (Dunnicliff 1988)

Observation Wells and Piezometer

Pipes (a), (c), and (d) are called piezometers because they indicate pore water pressure at one location (they are sealed above and below the perforated locations) and not to the groundwater pressure at other elevations

Pipe (b) in Figure above is an ***observation well***, because there are no subsurface seals that prevent a vertical connection between multiple strata

Observation Wells and Piezometer

A ***piezometer*** is a measuring device that is sealed within the ground so that it responds only to groundwater pressure around itself and not to groundwater pressure at other elevations

Observation Wells

Observation wells are usually vertical pipes with a slotted section at the bottom or a tube with a porous tip at the bottom. They are typically installed in boreholes with a seal at the surface to prevent surface water from entering the borehole. The depth to the water level is measured by lowering an electronic probe or weighted tape into the pipe.

Observation wells are appropriate only in a uniform, pervious material. In a stratified material, observation wells create a hydraulic connection between strata.

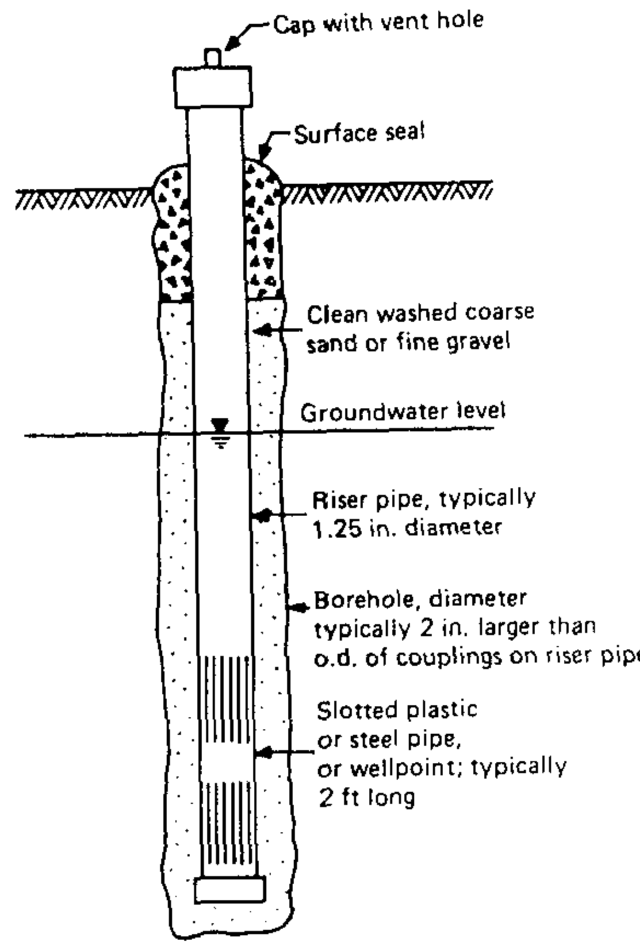
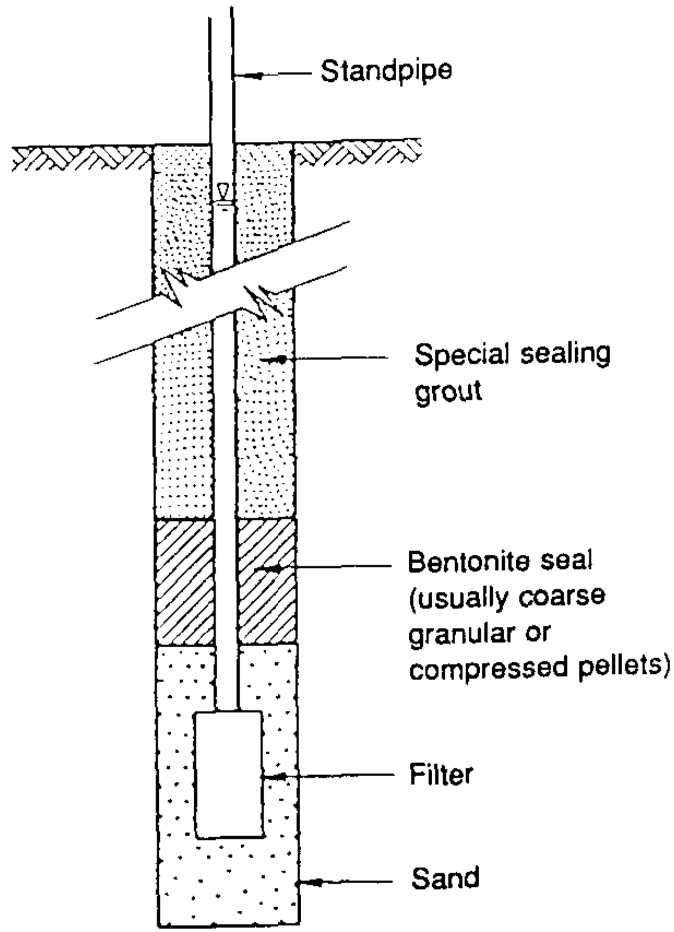


Figure . Schematic of observation well (Dunnicliff 1988)

Piezometer

- Excess pwp in core during compaction
- Uplift pressures
- Foundation head loss
- Core phreatic surface



Open Standpipe Piezometers

Open standpipe piezometers are with subsurface seals that isolate the strata to be measured.

They are simple, reliable, inexpensive, and easy to monitor

Seepage and Leakage

- *Seepage* is defined as interstitial movement of water through a dam, the foundation, or the abutments. It is differentiated from *leakage*, which is flow of water through holes or cracks.
- Seepage must be monitored on a regular basis to determine if it is increasing, decreasing, or remaining constant as the reservoir level fluctuates
- A flow rate changing relative to a reservoir water level can be an indication of a clogged drain, piping, or internal cracking of the embankment.
- Seepage may be measured using the following devices and methods:
    - Weirs (any shape such as V-notch, rectangular, trapezoidal etc.),
    - Flumes (such as a Parshall flume),
    - trajectory methods (for free flowing pipes and conduits),
    - Timed-bucket methods (volumetric method) and
    - Flow meters

At the small dams it is usually recommendable installing a triangular weir gauge at the downstream toe, at the central section of the dam, when possible,

Fig Leakage measurement using a triangular weir gauge

Water Quality

Seepage comes into contact with various minerals in the soil and rock in and around the dam. This can cause two problems:

- the chemical dissolution of a natural rock such as limestone, or
- the internal erosion of soil.

Dissolution of minerals can often be detected by comparing chemical analyses of reservoir water and seepage water. in a limestone area, one would look for calcium and carbonates, in a gypsum area, calcium and sulfates.

Other tests, such as pH can also sometimes provide useful information on chemical dissolution. Internal erosion can be detected by comparing turbidity of reservoir water with that of seepage water. A large increase in turbidity indicates erosion.

Seismic Loads

Seismic strong motion instrumentation records acceleration from earthquake shaking.

The data are used to evaluate the dynamic response of dams. Seismic acceleration and velocity are usually recorded with strong-motion accelerographs

How often should monitoring be carried out?

Type of Measurement	Frequency Of Measurements				
	Constructio	First Filling	First Year After Filling	Second And Third Years	Long-Term Operation
Visual Observation	Daily	Daily	Weekly	Monthly	Monthly
Reservoir Level	-	Daily to Weekly	Semi-monthly and at same time as any other measurements	Monthly and at same time as any other measurements	Monthly to quarterly and at same time as any other measurements
Tailwater Level	-	Weekly	Semi-monthly and at same time as any other measurements	Monthly and at same time as any other measurements	Monthly to quarterly and at same time as any other measurements
Drain Flow	-	Daily to Weekly	Weekly to monthly	Monthly	Monthly to quarterly
Seepage/ Leakage Flow	Monthly	Daily to Weekly	Weekly to monthly	Monthly	Monthly to quarterly
Pore Pressure/ Uplift	Daily to Weekly	Daily to weekly	Monthly	Monthly	Monthly to quarterly
Surface Settlement	-	Monthly	Quarterly	Semi-annually to annually	Semi-annually to annually
Surface Alignment	-	Daily to monthly	Quarterly	Semi-annually to annually	Semi-annually to annually
Internal Movement	-	Weekly to Monthly	Monthly to quarterly	Monthly to semi-annually	Monthly to annually
Joint/Crack Displacement	-	Weekly to Monthly	Monthly to quarterly	Monthly to semi-annually	Monthly to annually
Foundation Movement	Weekly	Weekly to Monthly	Quarterly	Semi-annually	Semi-annually to annually
Temperature	Hourly to weekly	Weekly	Semi-monthly	Monthly	Typically not required

The end of the course !

Thank you very much for your attention !