Typical Instruments for Monitoring Dam Safety

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Lord Kelvin (Sir William Thompson) 1824-1907

• “I often say . . . that when you can measure what you are speaking about, and express it in numbers, you know something about it...”
Why are you doing this? Focus on Potential Failure Modes

• Internal Erosion
• Embankment slope instability
• Concrete dam sliding or deformation
• Concrete deterioration
• After extreme loadings (earthquake or flood)
Why are you doing this? Focus on General "Health" of the Dam

- Settlement or deflection of embankment
- Displacement of appurtenant structures
- Concrete Performance
- Maintenance
For an existing dam:

• Understand the geology and design!

• Monitor for changes in:
  – Locations of visible seepage
  – Amount of seepage
  – Water pressures (piezometric levels)
  – Sediment that could be from internal erosion
  – Deformation or movement of embankment or concrete structures
Nature's Own Seepage Instrument

Picture taken in early springtime shows wetland grass and willows at toe, and sagebrush on hill.
Unchanged for 60 years, but without instruments, could we ever detect an increase in the seepage?
For a new dam:

• Understand the geology before you design it!
• Determine expected behavior of instruments
• Close monitoring (instruments and visual) embankment, foundation, abutments, and reservoir during first filling
  – Visible seepage
  – Measured seepage quantities
  – Rising piezometers
  – Settlement and deflection
  – Landslides
To answer these questions:

• Do observations agree with what the designers expected?
• If not, why not?
• Is there a dam-safety problem that requires action?
• Do we need more instrumentation, exploration, or analysis?
Seepage Quantity

- Assess effectiveness of constructed seepage barriers.
- Changes in flow could indicate progress of internal erosion.
- Sediment in weir box could be from wind or from internal erosion – check it!

V-notch weir – typically for smaller amounts of water
The Cipolletti or V-Notch Weirs may be similarly installed.
Seepage Measurements

- V-Notch Weirs for smaller quantities
Seepage Measurements

- Rectangular Weir
Seepage Quantity

- Weirs
- Compound
- Can be read as a V-Notch, Cipolletti or rectangular
Seepage Quantity

Flumes
- Parshall
- Cut Throat
- Palmer-Bowlus
- H-Flume
- Trapezoidal
Seepage Measurements

- Parshall Flumes, useful in a flat channel or when there is not much height difference.
Maintenance is necessary.
Seepage Measurements

- Bucket & Stop Watch, good for temporary use, or when there is no easy way to install a weir or flume.
Temporary monitoring for a new seep.
Flow Monitoring in Concrete Dams

- Formed Drains
- Foundation Drains
Monitoring Flows in Gutters in Tunnel or Gallery
Nature's Own Seepage Instrument
Picture taken in early springtime shows wetland grass and willows at toe, and sagebrush on hill.
Bright Green Vegetation on Dam Abutment in the Desert
Turbidity Monitoring

Portable installation: “Moment in Time” issue

Permanent installation: Monitoring the development of deposits on the mirrors and optical surfaces
Common Piezometers for Embankments and Foundations

• **Standpipe Piezometer**
  – Simple and robust
  – Requires drilling after construction
    • Drilling could damage embankment
    • Can only be installed where you can drill

• **Vibrating Wire Piezometer**
  – Can be installed in drill holes or buried in embankment during construction
  – Can be automated
  – Requires electronic readout and cables
  – More vulnerable to damage
• Pneumatic Piezometer
  – Installed during embankment construction
  – Requires readout apparatus
  – Small mechanical parts and limited service life

• Hydraulic Piezometer
  – Installed during embankment construction
  – Requires plumbing with no leaks and mechanical gauges
Open-Standpipe
Piezometers or Observation Wells
Piezometer or Observation Well?

Standpipe Piezometer
- Sealed with bentonite clay and cement grout above slotted portion
- Measures piezometric level (total head) at a specific depth.

Observation Well
- Not sealed
- Cannot detect differences in piezometric level at different depths only some rough average.
Why does that matter?
Piezometers on Section View

CPT PWP Dissipation Tests
Standpipe Piezometer Tip
Standpipe Piezometer Tip
Standpipe Piezometer Tip
Standpipe Piezometer Tip
Porous-tube Piezometers (PTP)

- Uses porous stone or plastic tip for fine-grained material
- 60 micron pore size is typical
- Placed in drill hole
- Use small diameter riser pipe for faster response.
Slotted-Pipe Piezometer (SPP)

- Used over longer intervals
- Used also as observation wells
- Used in gravelly or non-silty materials
- Usually plastic, sometimes stainless steel
- Slot width depends on material grain size; commonly 0.01 inch (0.25 mm)
Water Level Indicators for Reading Open-Standpipe Piezometers or Observation Wells
Transducers in Standpipes
Vibrating-Wire Piezometers
Buried or in Standpipe

Readouts provide Digits or Frequency
Digits = Hz²/1000
Digits are directly proportional to applied pressure

Example
- Pressure (psi) = (R₁ - R₀) x G
  where R = Digits read
  & G = Linear gauge factor
Vibrating-Wire Piezometers
Installation of Piezometers During Construction
Hydraulic Piezometers

Schematic of Closed Hydraulic Piezometer with Remote Readout (Twin-Tube)
Terminal Well

- At low elevation at the downstream toe of the dam
Pneumatic Piezometers
Piezometers Plotted With Time

What's happening here?
Piezometer Response to Changing Reservoir Levels
Uplift Pressure in Concrete Dams
Uplift Pressure Monitoring
Uplift Pressure Data
Length as required

Bourdon gage calibrated in feet of water

\[ \frac{3}{8} \text{" tube to } \frac{1}{4} \text{" i.p.s. male connector (brass)} \]

\[ \frac{1}{2} \text{" o.d. } \frac{1}{8} \text{" wall transparent plastic tubing} \]

\[ \frac{3}{8} \text{" tube to } \frac{3}{8} \text{" i.p.s. male connector (brass)} \]

1\" x \(\frac{1}{8}\"\) Hex bushing

1\" Elbow 1\" Pipe

\[ \frac{1}{2} \text{" Brass tee} \]

\[ \frac{1}{2} \text{" Gutter} \]

6C 6B
Instrumentation Categories

- Seepage
- Water Pressures
- Deformations
- Mass Concrete Performance
- Earth Pressures
- Automation of Instrumentation
Settlement and Deflection

- Survey markers on the embankment
  - Simple, but require surveyors or GPS to read them

![Survey marker image]

Diagram:
- Slope protection: 3 to 6 inch cobbles
- Material varies: fine and coarse, up to 2" in diameter, compacted earthfill
- 4" x 4" Schedule 40 PVC pipe
- Concrete backfill inside and outside of pipe
- 3:1 Sand cement grout
- #8 Rebar 8" long with finished top and a center punch hole 1/8" deep
- Approximate 6' diameter pad around settlement point
- ~2.5 m
Presentation of Settlement Data with Location and with Time
Baseplates and Crossarm Installations

Crossarm (steel channel)

Telescoping steel pipe
Settlement

- Base plate and riser for settlement during/after construction.

Casing Pipe (extend during construction)

Metal Rod (extend during construction)

Must place fill around casing.

Base plate placed on foundation before fill
Figure 12.29. Crossarm gage: (a) Schematic of pipe arrangement and (b) measurement probe (after USBR, 1974; courtesy of Bureau of Reclamation).
Maybe not a real good idea. (WAC Bennett Dam, Canada)

Don't let monitoring lead to a PFM.
Inclinometers

- Inclinometers measure the angle of inclination which is measured at a specific and repeatable depth.
- Inclinations of the casing are measured at various depths and used to compute a lateral movement profile.
- The bottom of the casing is anchored 15 feet below the zone of movement.

Diagram notes:
- Arrows indicate the direction of tilt of the top of the sensor.
- Uppermost wheel and digitilt sensor details are shown.
Deflection
• Inclinometers
45 cm movement on shear plane in shale bedrock
Piezometers and Inclinometers Shown on Section View of Embankment and Abutment

- Piezometer Readings
- 45 cm movement on shear plane in shale bedrock
- Inclinometer Casing Broken Here

RECLAMATION
IN-PLACE INCLINOMETER
MULTI-POSITION INSTALLATION
Borehole Shear Strip for Stability Monitoring
Multiple-Point Rod Extensometer

The IRAD GAGE Multiple-Point Rod Extensometer is designed for the measurement of deformations in soil or rock.

Head

Assumed to not move

A

B

C

Flat Wedge Borehole Anchor

Dial Indicator Readout

Quick-setting Cement

Measurement Rods

Alternative Anchor (Groutable)

PVC Pipe Coupling
Deformation Monitoring Using Plumblines
Figure 12.82. Inverted pendulum (courtesy of Soil Instruments Ltd., Uckfield, England).
Plumbline Measurement
Tiltmeters
Measurement Points
Crack or Joint Monitoring (Simple)
Scribe Marks at Contraction Joints

(Simple)

Inside Gallery
Three-Directional Offset Gauge at Jatiluhur Dam, Indonesia
Survey Targets on Structure
Vibrating-Wire Crack Gauge or Strain Gauge (not simple, but they can be automated)
Collimation System Monitoring
Temperatures in Concrete Dams

- During construction – concrete too hot from curing?
- After construction – progress of curing, temperature-induced stress, variation of stress and deformation with weather and reservoir level.

Thermocouple installed between lifts within RCC dam

Thermocouple installed under RCC

Cable-conduit to upstream face of dam

Thermistor and readout box
Earth or Total Pressure Cell
Considerations for Automation of Instrument Readings

• Are frequent readings needed (first filling, suspected problems, post-earthquake)?
• Is it difficult to collect the data manually (remote site, safety, winter or typhoon conditions)?
• Is the labor of manual readings very expensive?
• Is it difficult to get consistent readings manually (especially with changes in personnel)?
• Is it necessary to evaluate the data in "real time" (EWS)?
Some Cautions About Automation

• Make a realistic assessment of costs and benefits before deciding.
• Maintain manual reading capability for verification and backup.
• Provide redundancy in recording and communication.
• Provide simplicity and documentation so new personnel will be able take over operation.
• Consider future system support.
• Plan maintenance and periodic verification.
• Remember that automated instrumentation cannot replace human presence at the dam.
Discussion?