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APPENDIX B
FAILURE MODE ANALYSES

> It does not do to leave a live dragon out of your calculations, if you live near him.
>
> J. R. R. Tolkien

Failure mode analyses grew from some of technology's notable errors—failures such as NASA's *Challenger* loss. Most countries with agencies regulating dam safety encourage or require dam failure mode analyses to systematically examine vulnerabilities and sequences of events that could result in a loss of reservoir control. Results from the analyses identify monitoring requirements and actions needed to reduce or eliminate the probability that a progression of events will lead to a loss of reservoir control.

FMEA (failure mode effect analysis), FMECA (failure mode effect and criticality analysis), PFMA (potential failure mode analysis), and FMA (failure mode analysis) are terms used describe a method of analysis, which varies by jurisdiction; however, there are more similarities in the various methods than there are differences. Most follow this general sequence:

- Research the records of design and history of performance.
- Compare the records with acceptance criteria for dam safety.
- Visually inspect the dam and appurtenant structures.
- Propose potential failure modes such as those described in Chapters 3, 10, 11, and 12.
- For each potential failure mode, connect a required sequence of events, from initiation to resulting loss of reservoir control.
- Identify performance indicators that require surveillance and instrumented measurements to judge whether a dam is performing as expected.

- Evaluate findings from surveillance and instrumented measurements for indications that would suggest or rule out a failure sequence.
- Examine opportunities for intervention.
- Decide whether or not action is required.
- Propose enhanced performance monitoring and remedial action as needed.
- Document the results of the analysis for regular update or as conditions change.

When evaluating potential failure modes for a dam, it is important to evaluate a dam's performance, not as an isolated structure but rather as part of an overall system that includes not only the dam structure itself but also

- Foundation and abutments,
- Pipelines,
- Penstocks,
- Spillways,
- Outlet works,
- Gates and valves,
- Electrical systems,
- Control and data-acquisition systems, and
- Personnel who maintain and operate the dam.

Any part of the system has the potential to introduce a condition that could lead to failure or could allow a failure to progress. The entire system demands scrutiny.

A failure mode can consist of multiple individual events, often represented by nodes in an event tree, which can eventually lead to failure. Each event in the failure mode event tree has an individual likelihood or probability of occurring. A failure mode is established by describing a series of events connecting the initial condition to the breach. Fully characterizing a failure mode assists in developing surveillance and monitoring options by exhibiting the different points in the process when intervention can interrupt the sequence and action can be taken to prevent conditions from progressing to a loss of reservoir control.

POTENTIAL FAILURE MODE IDENTIFICATION

Typically, a team of qualified individuals conducts the analysis. Prior to the analysis, the team is tasked with completing a thorough review of all relevant background information on the dam including geology, design, analysis, construction, flood and seismic loadings, operations, dam safety evaluations, and existing performance-monitoring documentation, looking for potential unknown defects that could introduce a mechanism of failure.

In addition to the review of background information, the team also participates in a thorough site inspection, looking for clues that could indicate vulnerabilities in the dam's structures or its foundation. Ideally, the core team includes dam operators.

Typically, a team member or a designated outside individual leads or facilitates the session. This individual should have substantial prior experience with dam engineering to provide direction and organization during the failure mode session. A session begins with team members brainstorming and offering candidate potential failure modes based on the information gained during the preliminary review. For each loading condition, a potential failure sequence is described from initiating condition to loss of reservoir control.

If the team judges that a potential failure mode cannot progress completely to reservoir release, it is considered not to be credible and documented as such and excused from further consideration. A failure mode analysis considers all potential paths, not just structural behavior of the dam and its foundation but also gate failures, penstock breaches, and operational issues.

After identifying credible potential failure modes, the team records factors that make each more or less likely to occur. For example, an overtopping failure during a flood might depend on the existence of redundant spillways to reduce the probability of failure. Conversely, if an embankment dam has minimal freeboard and only one small spillway gate, both conditions are factors that may make the failure more likely.

If additional information or analyses to properly evaluate a candidate failure mode, the team recommends that additional information be gathered to complete the review.

EVALUATING PRIORITIES FOR ACTION

After identifying potential failure modes, the next step is to prioritize them. Prioritizing actions associated with potential failure modes helps a dam owner allocate resources in the most efficient manner. Each potential failure mode depends on how likely that failure process is to occur and what the consequences would be if it were to occur. Potential failure modes with the highest likelihood of occurring and have high consequences require a larger share of resources dedicated either to remediating or monitoring.

Setting priorities for each potential failure mode is carried out by assigning it to a category based on its likelihood and consequences. This process can be as simple as the team considering the factors making each potential failure mode more or less likely and estimating the consequences associated with it. The team then uses this information to come to a consensus on prioritization of potential failure modes. The definitions and relative levels of the categories can vary depending on the agency and the analysis. In general, evaluation should include a "high" category to highlight failure modes with high likelihood and high consequence, a "lower" category for failure modes that are less likely and low consequence, and a "lowest" category for failure modes that have a very low likelihood of occurring and few consequences. Additionally, evaluation provides for an additional category for potential failure modes lacking sufficient information to categorize.

Different combinations of consequence and likelihood can result in higher or lower categorization. For instance, a failure mode with very high consequences (a community of 10,000 people directly downstream, for example) with a relatively low likelihood of failure would typically be categorized as "high" category because of the high consequence associated with failure. Sound professional judgment is necessary to evaluate the relative levels of consequence and likelihood of each failure mode so they can be appropriately categorized.

Whether a numeric value or relative category, the results provide the basis for understanding, communicating, prioritizing, and managing the risks associated with the identified potential failure modes for a dam. Development and implementation of a program of action to reduce the risk associated with failure modes can occur after identification and prioritization of potential failure modes. Risk reduction measures can consist of additional study, implementation of new mitigation measures, changes to operation or maintenance practices, changes to the emergency action plan and/or the development of a surveillance and monitoring program designed to provide early detection of the identified potential failure modes.

SURVEILLANCE AND MONITORING

Assessing the performance of a dam involves evaluating information collected by visual surveillance and recorded instrumentation data against the expected performance of the dam based on design predictions and the potential failure modes.

Surveillance and monitoring provide the means for the early detection of the identified potential failure modes. The basis for the design of surveillance and monitoring program for identified potential failure modes targets where and how a performance indicator of a potential failure mode can be detected. Early detection provides the best opportunity to intervene to prevent failure, or to provide adequate warning so that the population at risk can be evacuated when failure is imminent or occurs.

The development of surveillance and monitoring program takes into consideration

- At what point can unexpected behavior or failure mode initiation be detected?
- Can instrumentation detect change in the performance indicators before a failure sequence progresses?
- Can a developing failure be detected visually?
- Are trained personnel available to review collected data and information in order to evaluate performance indicators of initiation or progression of a failure mode?
- How quickly might a failure mode develop once detected?
- How frequently should monitoring be performed?
- Will there be time to take action if a failure mode is detected?
- What actions should be taken to reduce the risk identified by surveillance and monitoring?

In summary, understanding the complete sequence of identified potential failure modes provides the basis for selecting the right combination of surveillance and instrumentation to develop a dam performance–monitoring program.

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APPENDIX C

RANGE, RESOLUTION, ACCURACY, PRECISION, AND REPEATABILITY

Watch every detail that affects the accuracy of your work.

Arthur C. Nielsen

Dance must have a precision without fault.

Arielle Dombasle

The 2000 *Guidelines for Instrumentation and Measurements for Monitoring Dam Performance* are contained in this appendix. They are repeated here to supplement Chapters 4 and 5 on planning and selecting instruments for measuring performance indicators.

To procure an appropriate system, the desired products need to be suitable for the intended use. Suitability can be determined by evaluating published performance specifications, which should take into consideration how to differentiate meaningful readings from meaningless noise. Understanding performance specifications is therefore critical for obtaining optimal results from a monitoring program.

Definitions of the many specifications that need to be considered are presented following. Among the most important are range, resolution, accuracy, precision, and repeatability. Because these are sometimes confused, their definitions and significance are discussed herein and illustrated in Fig. C-1. Performance specifications should be traceable to known standards, such as those maintained by the National Institute of Standards and Technology (NIST) in the United States.

Range specifies the highest and lowest values that the instrument is designed to measure. For example, the range limit for a piezometer might

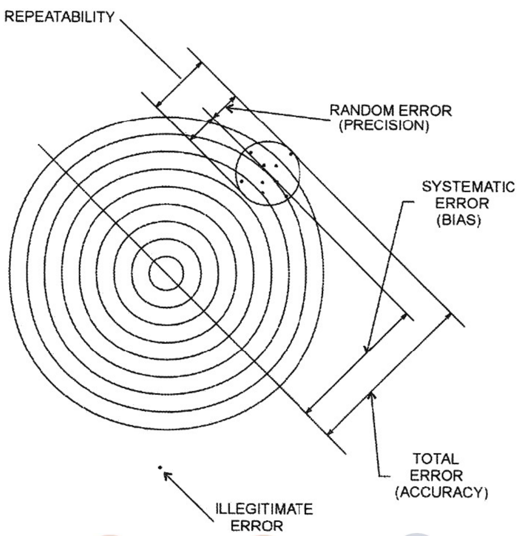

Fig. C-1. Precision, bias, error, and accuracy

be 0–50 psi. The expected range of the parameter to be measured must fall within the range limits of the instrument.

Span is related to range and is defined as the arithmetic difference between the upper and lower range limits. For example, a range of ±50 mm (1.96 in.) is equivalent to a span of 100 mm (3.93 in.), a range of –25° to +70°C (–13°F to 158°F) has a span of 95°C (203°F), and a range of 0–100 psi has a span of 100 psi.

Resolution is the smallest change in the measured parameter that can be distinguished by an instrument. The resolution is typically many times finer than the instrument's precision, repeatability, and accuracy. Resolution is the smallest change that can consistently and reliably be measured by an instrument.

Accuracy is the degree to which readings match an accepted standard (absolute) value and includes the combined effects of all sources of measurement error. Accuracy is written as a plus–minus (±) value, such as ±1 mm (0.03 in.), ±1% of reading, or ±1% of full span.

The accuracy number defines the maximum difference between the indicated value and the standard value when an instrument is used under specified operating conditions. These conditions include operation over the specified temperature range and input range of the instrument. The specified accuracy includes the combined effects of hysteresis, dead band, and repeatability and conformity errors. It is typically expressed in terms of the measured variable [e.g., ±2 mm (0.07 in.)] or as a percentage of the full-scale span (e.g., ± 5% of span).

Precision is the closeness of similar measurements to the arithmetic mean. It is expressed as a plus–minus (±) value. In dam monitoring, precision is often more important than accuracy because change, rather than absolute value, is of greatest interest.

Hysteresis is the dependence of the value of the output, for a given input, upon the history of prior excursions and the direction of the current traverse. It is usually determined by subtracting the value of the dead band from the maximum measured separation between upscale-going and downscale-going indications of the measured variable during a full-range traverse after transients have decayed.

Repeatability is the closeness of agreement of a number of consecutive measurements to one another under the same operating conditions. It is expressed in engineering units, such as 1 mm, or as a percentage of full-scale range. It is the closeness of agreement among a number of consecutive measurements of the output for the same value of the input under the same operating conditions approaching from the same direction for full-range traverses. It is usually measured as a non-repeatability and expressed as repeatability in percent of span. It does not include hysteresis.

The linearity is the closeness to which a curve (of instrument output versus input) approximates a straight line. It is usually measured as non-linearity (the maximum deviation between the curve and the straight line) and expressed as linearity, typically as a percentage of the full span of output of the instrument.

Conformity of a curve of actual output values is the closeness to which it approximates a specified curve (straight line, logarithmic, sinusoidal, etc.) of predicted output values. Linearity is a special case of conformity.

The dead band is the range through which an input can be varied without initiating observable response, usually expressed in percent of span.

For the output of a first-order system that is given a step input, the time constant is the time required to complete 63.2% of the total rise or decay.

Bias is the average indicated value of the measured variable that would result from an infinite number of measurements minus the actual value of the variable.

The calibration curve is a graphical representation of the measured output plotted versus known input values of the measured variable.

The scale factor is a number by which the measured output (millivolts, milliamps, frequency, polynomial, etc.) should be multiplied to compute the value of the measured variable.

Sensitivity is the ratio of the change in output magnitude to the change in the input that causes it after steady state has been reached. For a linear device, it is the inverse of the scale factor.

The temperature coefficient of the scale factor is the percentage change of scale factor per unit change of temperature of an instrument. This is also known as the temperature coefficient of the span.

The temperature coefficient of zero shift is the change from zero of measured output per unit change of instrument temperature in the absence of a change of input.

Long-term stability is an indication of the change in an instrument's output that would take place over a specified period of years in the absence of a change in the measured input (pressure, force, displacement, etc.). Because of the long time periods involved in gathering data and the diversity of factors that can contribute to output drift over these periods, precise answers can be elusive. However, publications discussing the long-term performance of most dam monitoring instruments are available and can be provided by the instrument manufacturers.

The electronic signal produced by the instrument determines how it will be read. The most common and robust analog signal types are DC voltage, DC current, and frequency. The most common digital signal types are RS232 serial output and RS485 serial output.

Specifications should include the output range of the signal, e.g., +/−5 V DC, from 4 to 20 mA, and other details that affect how the signal must be recorded.

Electronic instruments all require electrical power to operate. The power requirement specification should specify the acceptable voltage range of the input power, whether the voltage is AC or DC, the acceptable frequency range (if AC), and the current consumed by the instrument in amps or milliamps (mA). For DC-powered instruments, this specification should further state the amount of AC fluctuation or "ripple," typically expressed as a peak-to-peak voltage, that the instrument will tolerate and still function properly. The power specification should also state whether the instrument is protected from damage caused by power surges and power supply polarity reversal.

Furthermore, the power specification must state whether the instrument requires a regulated power supply, in other words, one that maintains a constant supply voltage, to obtain stable readings. For an instrument that requires regulated power, the output changes in proportion to the input voltage level. This change has nothing to do with the parameter being measured and can render a set of measurements useless. Many modern instruments regulate power with their own onboard electronics and therefore tolerate a wide range of input voltages. A "power requirements" specification for such an instrument might read, for example, "8–24 volts DC @ 8 mA, 250 mV peak-to peak ripple max., reverse polarity, short circuit and surge protected."

Whether an instrument requires regulated power or will operate stably with unregulated power is especially important in many dam applications where power must be supplied from variable power sources such as batteries or solar panels.

Although instrument specifications define instrument performance, the total performance of a monitoring system is also a function of the readout or data-acquisition equipment. For example, an instrument repeatability of 1 mm might be equivalent to an output repeatability of 1 mV. If the readout or data logger is unable to resolve changes smaller than 2 mV, the precision of the recorded data will be no better than 2 mm (0.07 in.). Electronic noises picked up in long cables or radio links between the instrument and the recording device can further degrade performance. It is important to evaluate the combined specifications of instrument and data-acquisition system and to suppress noise pickup to optimize results.

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APPENDIX D
GLOSSARY OF TERMS

I am still learning.
Michelangelo

Term	Definition
Absorption	Any dissipative loss mechanism resulting in reduction of acoustic amplitude; characterized by an energy conversion process.
Abutment	Valley side against which a dam is constructed. Right and left abutments are the respective sides looking downstream.
Accelerograph	Accelerometer having provisions for recording the acceleration of a point on the earth during an earthquake.
Accuracy	Degree of conformity of a measured or calculated value to its definition or with respect to a standard reference (see Uncertainty).
Acoustics	Field of science that focuses on the application and detection of sound waves.
Active storage	Volume of a reservoir available for withdrawal.
Afterbay	Downstream pool or tailwater area of a dam or turbine outlet.
Air-vent pipe	Pipe admitting air to an outlet conduit to modulate pressure during release of water.
Alignment surveys	Measuring survey monuments.

Alkali–aggregate reaction (AAR)	Chemical reaction of an aggregate with the alkalis or carbonates in cement, resulting in swelling and cracking of the concrete.
Alkali–silica reaction (ASR)	Chemical reaction between the alkalis in portland cement and some silicas, resulting in significant expansion in concrete, causing damage such as mass cracking.
Ambient air temperature	Temperature of the surrounding air at a dam.
Anchors	Post-tensioned wire strands or solid bars installed and stressed to improve stability.
Anemometer	Device that measures air speed.
Appurtenant structures	Water-retaining structures such as an outlet, spillway, powerhouse, or tunnel.
Aqueduct	Channel for conveying water.
Aquifer	A permeable body of rock saturated with groundwater.
Aquitard	A bed of low permeability forming a groundwater barrier.
Arch buttress dam	Individual arched segments supported by buttresses.
Arch dam	Concrete or masonry dam that is curved to transmit load to the abutments.
Attenuation	Loss of energy away from an earthquake epicenter.
Autogenous growth	Self-generating growth produced without external influence.
Automated Data-Acquisition System (ADAS)	System for monitoring the performance of a dam that includes components for data collection that are permanently installed and programmed to operate without human intervention.
Auxiliary spillway	Spillway in addition to a service spillway.
Axis of dam	A straight or curved line along the centerline of the crest.
Barometer	Absolute pressure gauge to measure atmospheric pressure.
Bentonite	Clay largely composed of montmorillonite and beidellite formed from volcanic ash decomposition.
Berm	Horizontal step or bench in the sloping profile of an embankment dam.

Borros point anchor	Extensometer with a single anchor point in which the elevation of the top of a rod is measured with respect to a collar.
Bourdon tube	Mechanical measuring instrument employing a curved or twisted metal tube flattened in cross section as its sensor.
Buoyancy	Resultant vertical force exerted on a body by a static fluid in which it is submerged or floating.
Buttress dam	Dam consisting of a watertight upstream face supported at intervals on the downstream side by a series of buttresses.
Calibration	Determining by measurement or comparison with a standard the current value of each scale reading on a meter or other device.
Carlson meter	Any of a family of strain- or temperature-monitoring instruments that incorporate hand-wound nickel-chromium wire sensing elements in a half-bridge resistance measurement circuit.
Cavitation	Emulsification produced by disruption of a liquid into a liquid–gas two-phase system when the hydraulic pressure of the liquid is reduced to the vapor pressure.
CFM	Cubic feet per minute.
CFS	Cubic feet per second.
Cofferdam	Structure enclosing all or part of a construction area so that construction can proceed in a dry area.
Cohesionless	Granular soil in which strength is directly related to confining stresses.
Cohesive soil	Very fine-grained plastic soil in which strength depends upon moisture content.
Concrete lift	Vertical distance between successive horizontal construction joints.
Conduit	Closed channel for conveying water.
Consolidation	Process of increasing soil density either naturally or mechanically.
Consolidation grouting	Injection of grout along discontinuities to consolidate rock.
Construction joint	Bonded interface between two successive placements of concrete.

Constantan	Copper–nickel alloy known for electrical stability with temperature change that is used in common thermocouple compositions.
Core	Barrier of impervious material to retard seepage through the body of an embankment dam.
Crack meter	Device that measures change in the width of a crack.
Creep	Time-dependent strain of solids.
Crest length	Length of the top of a dam.
Crest of dam	Top of dam.
Crest wall	Parapet on dam crest.
Crib dam	Timber boxes filled with earth or rock.
Crustal zone	Outermost solid layer of the earth.
Culvert	Conduit under a road, railway, or embankment.
Cutoff wall	Wall of impervious material built into the foundation to reduce seepage under a dam.
CY	Cubic yard.
Data logging	Conversion of electrical impulses from instruments into digital data to be recorded in various types of memory.
Dead storage	The storage that lies below the invert of the lowest outlet and that cannot be withdrawn from the reservoir.
Deformation	Alteration of shape or dimensions.
Dental work	Removal of loose rock and soil from a dam, abutments, and foundation contact areas and the placement of backfill concrete.
Dewatered	Area previously containing water that has since been drained.
Differential movement	Difference in movement between two objects or points.
Dispersion	Two-phase fluid system in which one phase is finely dispersed (on colloidal dimensions) within a continuous liquid phase.
Dissolution	Dissolving.
Diurnal	Daily.
Diversion channel, canal, or tunnel	Waterway to divert water from the work.
Double-curvature arch dam	Arch dam that is curved vertically as well as horizontally (ellipsoidal shape).

Drainage area	Area that gathers water.
Drainage layer (blanket)	Layer of permeable material to facilitate drainage.
Drainage well (relief well)	Well to collect seepage through or under a dam.
Drawdown	Releasing water to lower the reservoir water surface.
Earth dam	Embankment dam in which more than 50% of the total volume is formed of compacted finer-grained materials than rockfill material.
Easting	Distance from one point to another in the easterly direction.
Elastic properties	Properties that allow a material to sustain deformation without permanent loss of size or shape.
Electrolytic tiltmeter	Tiltmeter that uses liquid-filled electrolytic spirit level as the sensing element.
Embankment dam	Dam constructed of natural materials (soil and rock).
Emergency gate	Standby or reserve gate used when the normal means of water control are not available.
Equipotential lines	Lines representing surfaces on which the water potential (pressure + elevation head) is the same at every point.
Error	Difference of a measured value from its known true or correct value (or sometimes from its predicted value).
Extensometer	Measures the change in distance between two anchored points.
Failure mode	Sequence of events exploiting weakness that progress until reservoir control is lost.
Failure surface	Surface upon which the strength of a material resisting shear is exceeded.
Fetch	Distance over a body of water traversed by waves without obstruction.
Flat jack	Hollow steel cushion made of two nearly flat disks welded all around the edge that can be inflated with oil under controlled pressure.
Flood surcharge pool	Volume of reservoir above the normal water surface and the maximum water surface during a flood.

Flume	Open channel constructed of concrete, steel, or wood used to convey water.
Forebay	Reservoir immediately upstream from an outlet.
Frequency	Number of peak-to-peak cycles per unit time characterizing a sinusoidal sound wave; typically given in units of millions of cycles per second or MHz.
Gage or gauge	An apparatus that measures something with a graduated scale.
Geodimeter	Geodetic distance meter.
Geoid	Shape of the entire earth at sea level.
Geo-synchronous satellite	Satellite that orbits the earth from west to east so as to remain fixed over a given place on the earth.
Geosynthetic	Membrane of woven or unwoven fabric.
Graded filter	Sand and gravel proportioned to permit passage of water without movement of finer material.
Gravity dam	Dam that depends on its weight for its stability.
Grout blanket	Shallow band of drill holes grouted with concrete to consolidate the foundation (consolidation grouting).
Grout curtain	Drilled holes filled with grout under pressure to form a cutoff under a dam.
Headwater	Elevation of the free water surface on the upstream side of the dam.
Headwaters	Source of waters in a river.
Homogeneous dam	Embankment dam constructed of similar earth material throughout.
Hydraulic fill dam	Embankment dam constructed of materials conveyed and placed by flowing water.
Hydraulic fracture	Fracture from pore water pressure exceeding soil strength.
Hydrogeology	Science dealing with groundwater.
Hydrograph	Graphical representation of stage, flow, velocity, or other characteristics of water at a given point as a function of time.
Hydrostatic pressure	Pressure at a point in a fluid from the weight of fluid above it.
Hysteresis plot	Plot describing changes in measurements relative to prior measurements.
Impermeable liner	Liner that will not permit water or other fluid to pass through.

Impervious soil	Soil with low permeability.
Inclinometer	Instrument for measuring the angle of deflection between a reference axis and a casing axis.
Inclinometer casing	Specially constructed casing fitted with slots or channels to prevent a probe-type inclinometer from rotating when lowered or raised.
Inflatable dam	Dam constructed of rubber or other watertight membrane that increases in vertical height when inflated.
Initial filling	First filling of a reservoir or other water-retaining structure.
In situ pore pressure	Pore pressure prior to any external influence.
Inverted pendulum	Pendulum anchored at its lowest point in rock or concrete to allow the upper floated end to move freely for the measurement of vertical change.
Joint meter	Device used to measure the movement of a joint in concrete or any other material.
kWh	Kilowatt-hour (1,000 watt hours).
Lateral translation	Horizontal movement.
Leakage	Rapid movement of water or other liquid through a porous medium such as through a dam, its foundation, or abutments.
Liquefaction	Change in saturated soil to a liquid or near-liquid state.
Longitudinal cracking	Cracking parallel with a dam axis.
Masonry dam	Dam constructed mainly of stone, brick, or concrete blocks jointed with mortar.
Maximum section	Cross section with the greatest difference between the base of a dam and its crest.
Measurement range	Highest and lowest values that an instrument is designed to measure.
Membrane dams	Dam with a watertight barrier on the upstream face.
Modulus of elasticity	Ratio of stress to strain in elastic media.
MPa	Mega-Pascal (1 million Pascals).
Multiplexer	Device for distributing many signals into a smaller number of measurement channels.
Multipoint extensometer	Extensometer that can measure movement between several anchored locations along its length.
Mw	Megawatt (1 million watts).
Nappe	Shape of water flowing over a barrier at its crest.

Northing	Distance from one point to another in the northerly direction.
Observation well	Well drilled to observe water level.
Offset	Difference between actual and reference values.
Open piezometer	Observation wells with subsurface seals that isolate the strata to be measured.
Overtopping	Water flowing over a dam.
Parshall flume	Calibrated device for measuring the flow of water in open conduits.
Pendulum (plumbline)	Rigid body mounted on a fixed horizontal axis, about which it is free to rotate under the influence of gravity.
Penstock	Pipe between the intake and the turbine of a hydroelectric unit.
Phase	Measure of a fraction of the period of a repetitive phenomenon measured with respect to some distinguishable feature of the phenomenon itself.
Phreatic line	Line below which soils are saturated.
Piezometer	Instrument for measuring fluid pressure (air or water) within soil, rock, or concrete.
Piping	Progressive development of movement of soil by seepage that progresses from downstream to upstream.
Pitot tube	Velocity-measuring device for a fluid stream.
Pneumatic piezometer	Piezometer with a porous filter connected to two tubes that measure pressure across a flexible diaphragm between them.
Poisson's ratio	Ratio of the horizontal to vertical strain under load.
Pore pressure	Interstitial pressure of fluid (air or water) within a mass of soil, rock, or concrete.
ppm	Parts per million.
Precision	Degree of mutual agreement among a series of individual measurements. Precision is often but not necessarily always expressed by the standard deviation of the measurements.
psi	Pounds of force per square inch.
Radiotelemetry	System used to provide a communication or control channel between two specific points.
Rain gauge	Instrument designed to collect and measure precipitation.

Relative density	Ratio of density of soil with reference to its maximum possible density for a given compaction effort.
Repeatability	Ability of a device to measure the same value repeatedly.
Reservoir drawdown	Reducing the water level in a reservoir.
Reservoir rim	Intersection of the reservoir water surface with the containing basin ground surface.
Resolution	Smallest increment of a measurable property.
Rockfill dam	Embankment dam in which more than 50% of the total volume comprises compacted or dumped pervious natural or crushed rock.
Saturation pipes	Groundwater monitoring well to determine the level of the groundwater.
Scour	Erosion caused by the flow of air, ice, or water.
Seepage	The slow movement of water or other liquid through a porous medium such as through a dam, its foundation, or abutments.
Seepage paths	The path that seepage follows.
Seepage quality	Level of turbidity and dissolved solids in the seepage.
Seepage quantity	Measurement of seepage volume.
Seismic response	Vibration of a dam from earthquake shaking.
Seismicity	Phenomena of the earth's tectonic movements.
Seismo-tectonics	Process of crustal plate movement that generates earthquakes.
Sensor	Device that responds to a physical stimulus and transmits a resulting signal.
Settlement	Decrease in elevation of a point on a dam's surface.
Settlement gauge	Instrument that measures elevation changes between two or more points.
Shear strength	Ability of a material to resist forces tending to cause movement along an interior planer surface.
Shear zone	Zone where the shear strength was exceeded and some permanent deformation (sliding) occurred.
Signal conditioning	Electronic circuitry used for converting transducer outputs into signals suitable for transmission over cable or radio and for recording by data loggers and other devices.

Slope failure	Downward and lateral movement of soil beneath a natural or constructed slope.
Snow course	Designated open area where measurements of snow cover are made to determine its water equivalent.
Sound velocity (ultrasonic velocity)	Speed at which sound waves travel, which depends on the physical properties of the material in which it is propagating; typically denoted by symbol *c*; sound velocity is usually measured by time-of-flight methods.
Stability	Resistance against movement routinely expressed as a factor of safety.
Staff gauge or stage recorder	Graduated scale placed in a position so that the level of water may be read directly.
Standards	Commonly used and accepted as an authority.
Standpipe	Vertical tube filled with water, also known as an open-well piezometer.
Strain gauge	Device that measures the change in distance between two points.
Strain rosette	Pattern of intersecting lines on a surface along which linear strains are measured to better define the three-dimensional distribution of strain about a point.
Stress meter	Instrument that measures stress directly.
Strong-motion accelerometer	Accelerometer designed to record ground shaking from strong earthquakes while remaining insensitive to smaller events.
Suspension	Two-phase system consisting of solid particles suspended in a liquid medium.
Tailwater	Elevation of the free water surface (if any) on the downstream side of a dam.
Tendon	*See* Anchors.
Theodolite	Optical instrument used in surveying. It consists of a sighting telescope mounted so that it is free to rotate around horizontal and vertical axes so that the angles can be measured.
Thermistor	Resistive circuit component having a high negative temperature coefficient of resistance, so that its resistance decreases as the temperature increases.

Thermocouple	Device consisting basically of two dissimilar conductors joined together at their ends measuring voltage as an indicator of temperature.
Thermometer	A device for measuring temperature in Fahrenheit or Celsius.
Tiltmeter	Instrument used to measure rotational movement with respect to gravity.
Total pressure cell	Gauge, usually consisting of a piezometer connected to an enclosed fluid cell that then measures the total load applied to the cell.
Total station	Surveying instrument that measures distance plus vertical and horizontal angles.
Transducers	Device or element that converts an input signal into an output signal of different form.
Trigonometric levels	Method of determining the difference of elevation between two points by using the principles of triangulation and trigonometric calculations.
Trilateration	Measurement of a series of distances between points on a surface of interest to establish their relative positions.
Trunnion friction	Friction created from the movement of a pin or pivot on bearings of gate trunnions.
Turbidity meter	Device that measures the loss of a light beam as it passes through a solution with particles large enough to scatter the light.
Uncertainty	Limits of the confidence interval between a measured and calculated quantity.
Undrained	State of strain that restricts pore water pressure dissipation from a body of soil.
Uplift	Upward pressure against the base of a dam.
Upstream blanket	Impervious layer placed on the reservoir floor upstream of a dam.
Vibrating-wire piezometer	Electrical piezometer that measures in situ pressure by changes in signal frequency.
Weir	Device in a channel that serves to regulate water level or measure flow.
Zoned embankment dam	Embankment dam composed of zones of selected materials having different degrees of porosity, permeability, and density.
Zoned rockfill dam	Embankment dam constructed of rock with internal core, filter, and drain zones.

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