Projeto de Barragens e Diques

Instrumentação e Monitoramento

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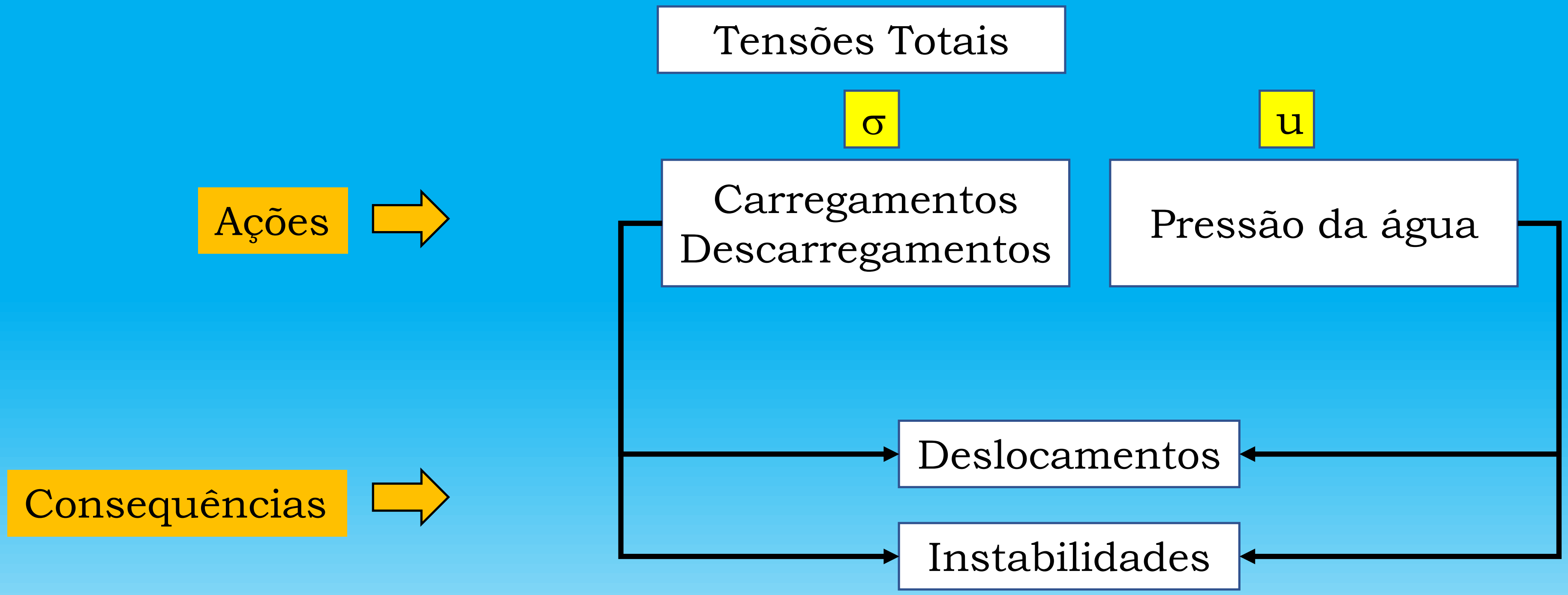
Monitoramento

O objetivo da instrumentação é permitir o monitoramento, que por sua vez objetiva acompanhar o comportamento da barragem para:

- Avaliar se o funcionamento está de acordo com o esperado e previsto no projeto
- Alertar para eventuais problemas que possam gerar alteração na segurança da barragem

Monitoramento



Instrumentação

As principais causas de acidentes ajudam a entender o projeto de instrumentação.

- Recalques excessivos do maciço
- Recalques excessivos de tubulações
- Trincas devido a recalques
- Piping nas ombreiras
- Piping em contato com estruturas de concreto
- Piping no aterro
- Piping na fundação
- Instabilidade dos taludes (final de construção, operação e rebaixamento rápido).
- Ruptura pela fundação
- Liquefação
- “overtopping”

Instrumentação

Cada instrumento deve ter um propósito e todos devem:

- Não havendo um propósito não deve ser instalado.
- A manutenção deve ser possível e fácil.
- A calibração deve ser feita e verificada.

O melhor instrumento é a observação visual do profissional experiente, tanto dos dados dos instrumentos como de inspeções ao local

Instrumentação

Quantos instrumentos devemos instalar?

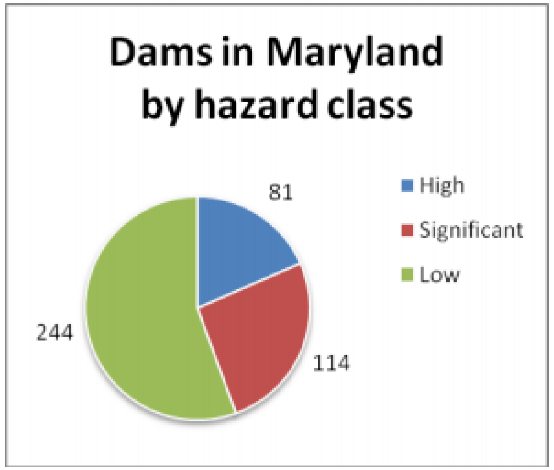
Qualquer barragem que possa afetar áreas habitadas deve ter algum monitoramento.
A quantidade de instrumentos está associada a informação necessária para que se possa avaliar a segurança.
Pode-se ter barragens com monitoramento visual apenas.
Pode-se ter barragens com monitoramento de pressão de água, tensões totais, movimentos superficiais, movimentos internos, etc.

Qualquer que seja o instrumento ele deve permitir entender e representar toda a estrutura monitorada.

Classificação dos riscos potenciais envolvidos com barragens

- **Minimal Hazard Potential** - failure of the dam would likely result in no economic loss beyond the cost of the structure itself and losses principally limited to the owner's property.
- **Low Hazard Potential** - failure of the dam would result in no probable loss of human life and in low economic loss. Failure may damage storage buildings, agricultural land, and county roads.
- **Significant Hazard Potential** - failure or misoperation of the dam would result in no probable loss of human life but could result in major economic loss, environmental damage, or disruption of lifeline facilities. Failure may result in shallow flooding of homes and commercial buildings or damage to main highways, minor railroads, or important public utilities.
- **High Hazard Potential** - failure or misoperation of the dam resulting in loss of human life is probable. Failure may cause serious damage to homes, industrial or commercial buildings, four-lane highways, or major railroads. Failure may cause shallow flooding of hospitals, nursing homes, or schools.

Nebraska Department of Natural Resources



High Hazard Dam - Failure would likely result in loss of human life, extensive property damage to homes and other structures, or cause flooding of major highways such as State roads or interstates. High Hazard dams are referred to as "Category I" dams in the Code of Maryland Regulations (COMAR 26.17.04.05) and "Class C" ponds by the US Natural Resources Conservation Service (NRCS). There are 81 high hazard dams in Maryland.

Significant Hazard Dam - Failure could possibly result in loss of life or increase flood risks to roads and buildings, with no more than 2 houses impacted and less than six lives in jeopardy. These are referred to as "Category II" dams in COMAR and "Class B" by NRCS. There are 114 significant hazard dams in Maryland. (As of February 2015)

Low Hazard Dam - Failure is unlikely to result in loss of life and only minor increases to existing flood levels at roads and buildings is expected. These structures are referred to as "Category III" dams in COMAR and "Class A" by NRCS. There are more than 240 low hazard dams in Maryland.

Danger Reach

The area below a dam that would be flooded as a result of dam failure is called the "**Danger Reach**." The depth of flooding from a dam failure is generally much greater than the normal floodplain, as

Maryland Department of the Environment

O projeto do sistema de instrumentação e monitoramento está associado a este tipo de classificação.

Instrumentos típicos para monitoramento de barragens

Quantity Measured	Instrument	Remarks
Vertical Displacements	● Hydrostatic levels ● Precision topographic levelling devices ● Extensometers ● Theodolite ● Settlement gauges	● Measure upward (heave) and downward displacements.
Angular Displacements	● Clinographs ● Clinometers ● Slope indicators	
Horizontal Displacements	● Direct or inverted pendulums ● Theodolites ● Collimation ● EDMI	
Strain	● Strain gauges	● The principle purpose is to measure the state of stress in a plane parallel to the external face of the structure. Preferably their are embedded in the concrete during construction.
Settlement	● Settlement meters ● Levelling instruments ● Wire and bar strain gauges ● Cross-arms (USBR type)	● Measurements taken of the foundation (for any type of dam) or the dam proper (for earth and rockfill dams). ● Used for detecting individual layers of the embankment.
Uplift and Pore Pressure (also water tables or ground water level)	● Piezometers (open or closed types) ● Water gauges ● Pressure gauges	
Seismic Movements	● Seismographs ● Accelograph (or displacement recorders)	● Strong motion type of accelographs are used detect ground motion frequencies in the foundation, at different points on the dam. Seismographs are used to record earthquakes near the reservoir area.
Humidity	● Hydrometers	● Measurements are taken of the air and in the dam.

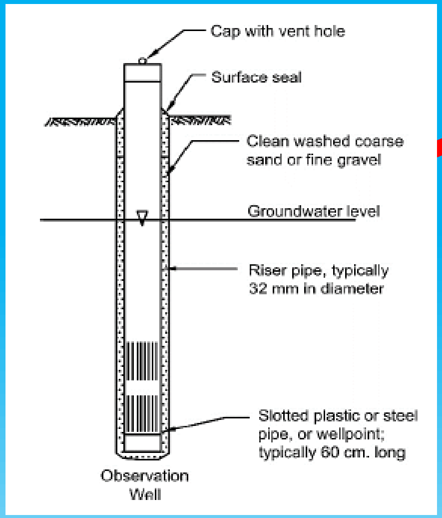
Quantity Measured	Instrument	Remarks
Temperature	● Mercury thermometers ● Thermoelectric couple ● Vibrating wire thermometers	● Measurements of air and within the body of the structure (particularly important for concrete dams).
Rainfall Measurements	● Rain gauges	
Leakage and Flow	● Flumes and weirs with different systems of measurements (optical, electrical or mechanical)	● Measurements are taken of seepage, leakage and drainage flow in selected parts of dam.
Turbidity	● Turbidity-meters	● Measure quantity of fine materials and chemicals suspended in the water in the downstream side of the dam.
Water Level Measurements	● Pneumatic level gauges ● Float system ● Stadia rod system ● High precision hydrostatic balance	● Measurement of depths in the reservoir.
Joint and Crack Measurements	● Joint meters ● Deformeters	● Measurements of variations in the openings and sliding of joints and fissures.
Stress	● Direct stress meters (or gauge) ● Direct strain gauge	● Measurements of tension and compression stresses. They are design for direct measurement of stresses without resorting to the modulus of elasticity.

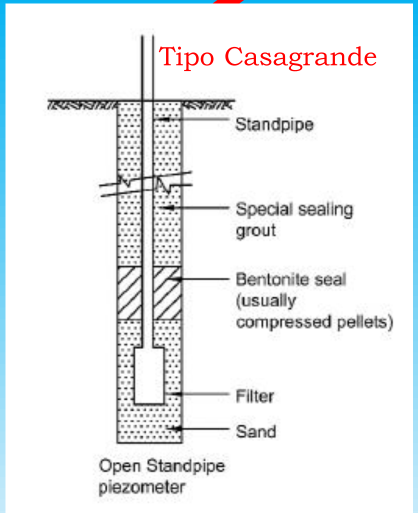
(ICOLD, 1982, 1988)

Instrumentação predominante em barragens de terra

- Medidores de pressão de água
- Medidores de tensão total
- Medidores de deslocamentos

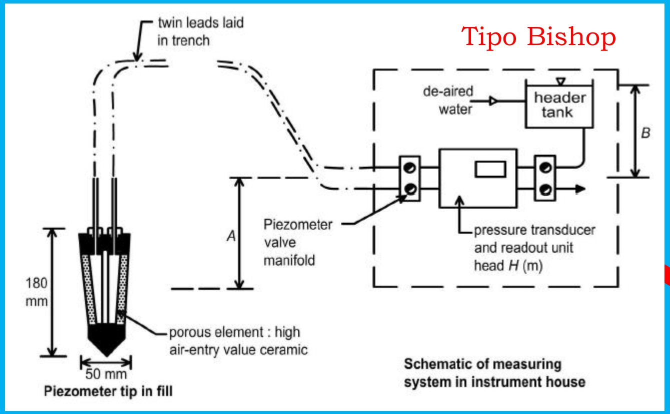
Medidores de pressão de água

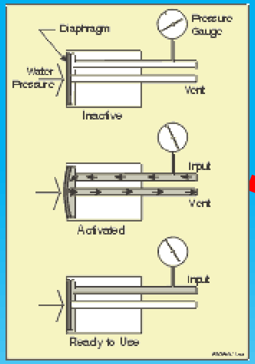


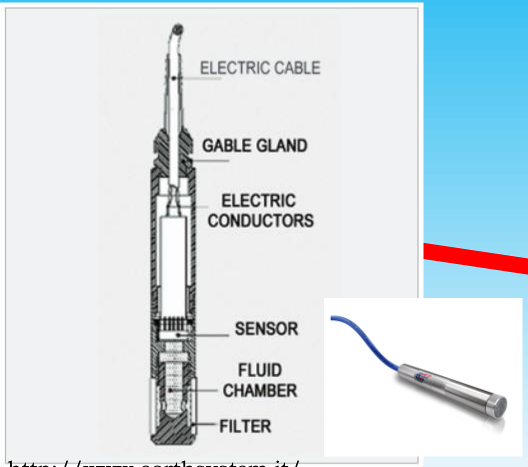


TYPE	ADVANTAGES	LIMITATIONS
Staff Gage	Simple device, inexpensive, reliable.	Cannot be automated.
Float-Type Water Level Gage	Simple device, inexpensive, reliable. Easily automated.	Requires readout device. Sensor must be in water. Must be protected from ice.
Ultrasonic Water Level Sensor	Simple device, inexpensive, reliable. Sensor does not touch water. Easily automated.	Requires readout device. Must be corrected for air temperature. Debris, foam, and ice can cause false readings.
Bubbler	Simple device, inexpensive, reliable. Easily automated.	Requires readout device. Sensor must be submerged in water.
Observation Well	Simple device, inexpensive. Easily automated.	Applicable only in uniform materials, not reliable for stratified materials. Long lag time in impervious soils.
Open Standpipe Piezometer	Simple device, inexpensive, reliable. Simple to monitor and maintain. Standard against which all other piezometers are measured. Can be subjected to rising or falling head tests to confirm function. Easily automated.	Long lag time in impervious soils. Potential freezing problems if water near surface. Porous tips can clog due to repeated inflow and outflow. Not appropriate for artesian conditions where phreatic surface extends significantly above top of pipe. Interferes with material placement and compaction during construction. Can be damaged by consolidation of soil around standpipe.
Closed Standpipe Piezometer	Same as for open standpipe piezometers.	Same as open standpipe piezometer but appropriate for artesian conditions.
Twin-tube Hydraulic Piezometer	Simple device, moderately expensive, reliable, long experience record. Short lag time. Minimal interference with construction operations.	Cannot be installed in a borehole, therefore, generally not appropriate for retrofitting. Readout location must be protected from freezing. Moderately complex monitoring and maintenance. Periodic de-airing required. Elevation of tubing and of readout must be less than 10 to 15 feet above piezometric elevation. Can be automated, but moderately complex.
Pneumatic Piezometer	Moderately simple transducer, moderately expensive, reliable, fairly long experience record. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems.	Moderately complex monitoring and maintenance. Dry air and readout device required. Can be automated, but not over long distances. Sensitive to barometric pressure. Automation is complex. Moderately expensive readout.
Vibrating Wire Piezometer	Moderately complex transducer. Simple to monitor. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems. Frequency output signal permits transmission over long distances. Easily automated.	Lightning protection required. Expensive transducer and readout. Sensitive to temperature and barometric pressure changes. Risk of zero drift, but some models available with in-situ calibration check.
Bonded Resistance Strain Gage (Electronic) Piezometer	Moderately complex device, expensive. Simple to monitor. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems. Easily automated.	Lightning protection required. Subject to zero-drift, therefore, not recommended for long-term monitoring. Expensive transducer and readout. Voltage or current output signal sensitive to cable length, splices, moisture, etc.

Medidores de pressão de água







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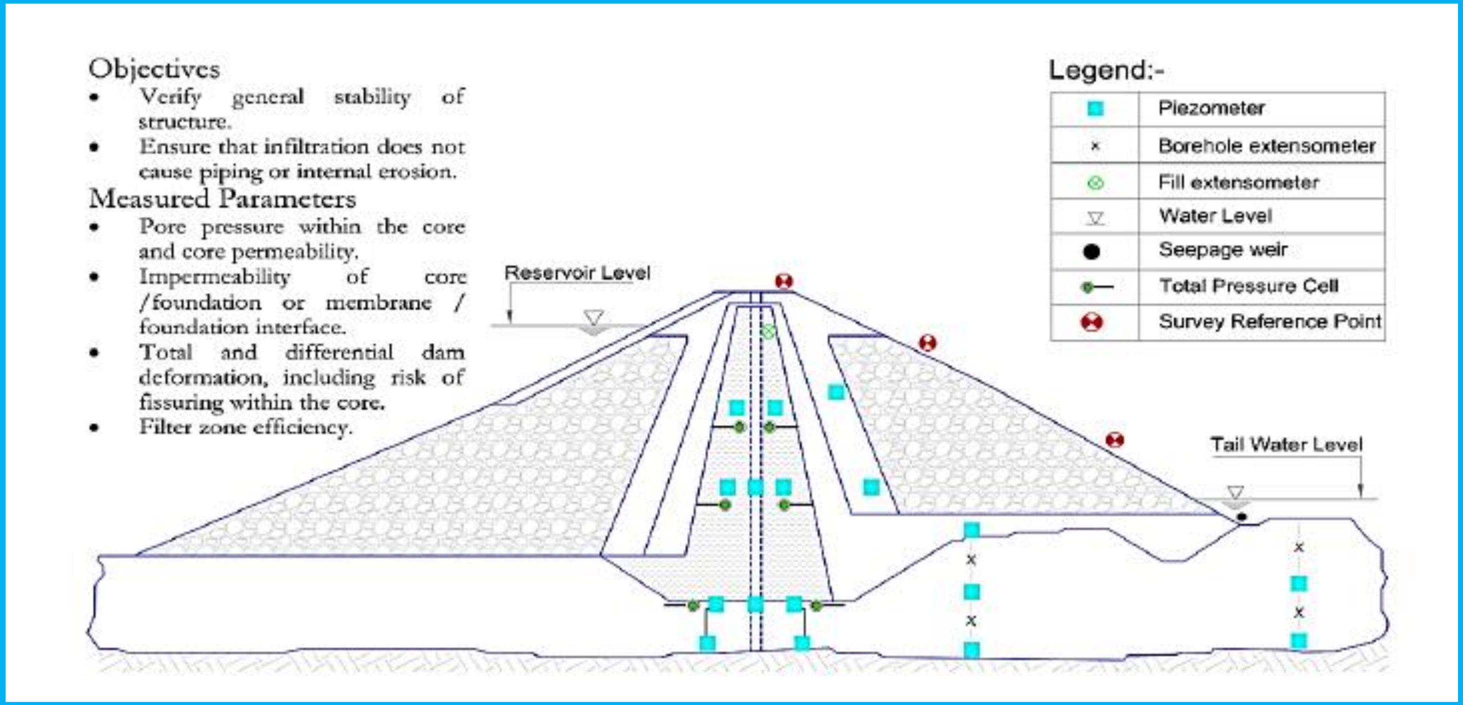
http://www.earthsystem.it/

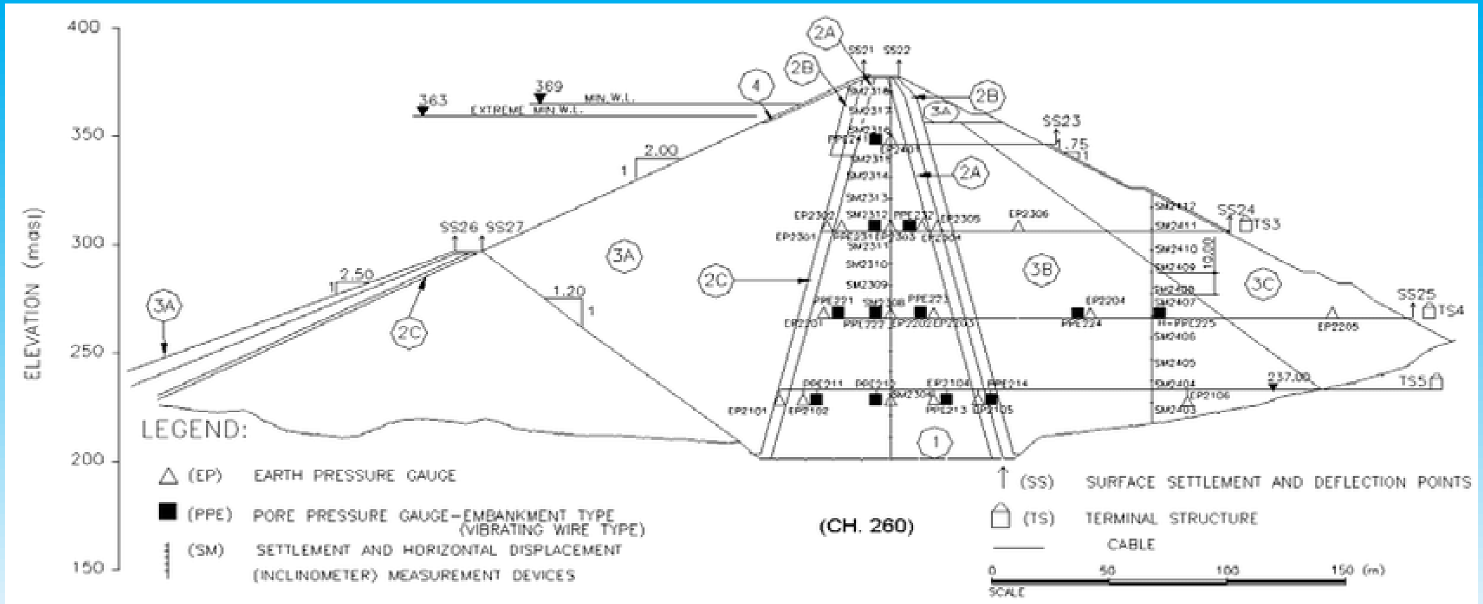
Parâmetros a serem monitorados e os respectivos instrumentos

Structure Type	Feature	Visual observation	Movements	Uplift and pore pressure	Water levels and flow	Seepage flows	Water quality	Temperature measurement	Crack and joint measurement	Seismic measurement	Stress-strain measurement
Embankment Dams	Upstream slope	●	●	●	●	–	–	–	–	●	–
	Downstream slope	●	●	●	–	●	●	●	●	●	–
	Abutments	●	●	●	–	●	●	●	–	●	–
	Crest	●	●	●	–	–	–	–	●	●	–
	Internal drainage system	–	–	●	–	●	●	●	–	–	–
	Relief Drain	●	–	●	–	●	●	–	–	–	–
	Riprap and other slope protection	●	–	–	–	–	–	–	–	–	–

Seções Instrumentadas

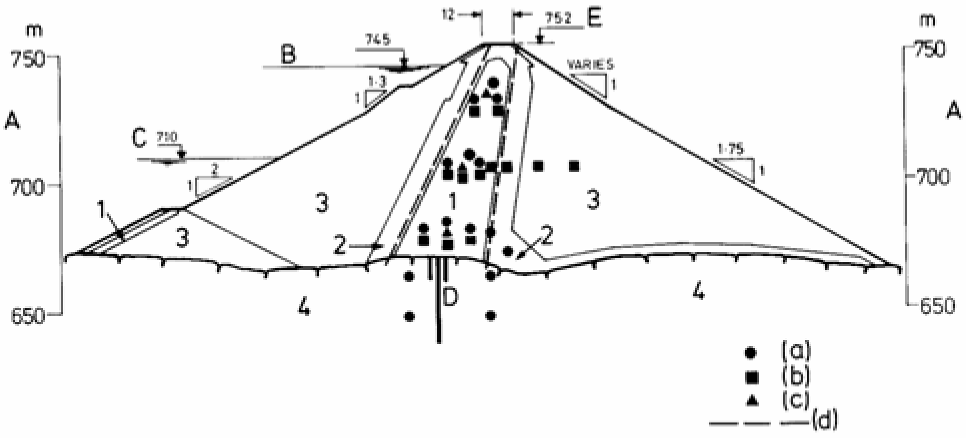


DRIP (2018)



Akhtarpour et al. 2006

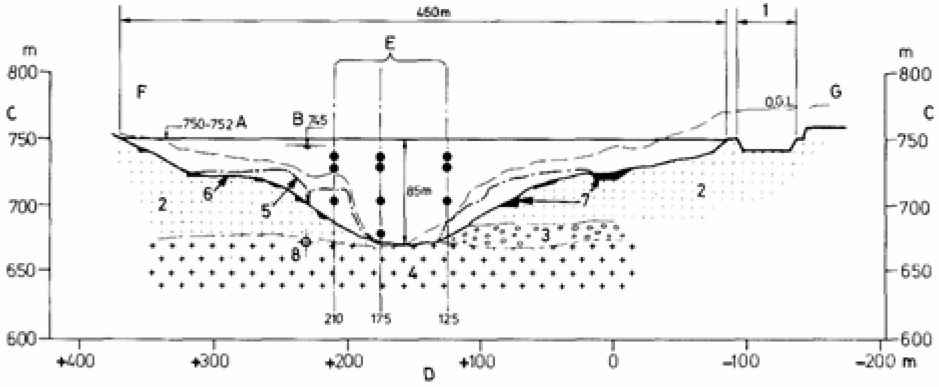
Seções Instrumentadas



Dam Cross Section and Instrumentation at Ch. 175

A. Elevation
B. Full supply level
C. Minimum operating level
D. Grout curtain
E. Includes settlement allowance
1. Core
2. Filters, drains and transitions
3. Rockfill
4. Monzonite
a. Hydraulic piezometer
b. Hydraulic settlement cell
c. Group of earth pressure cells (measuring in 3 directions)
d. Deformation tube

Varies



Longitudinal Profile along Core Trench

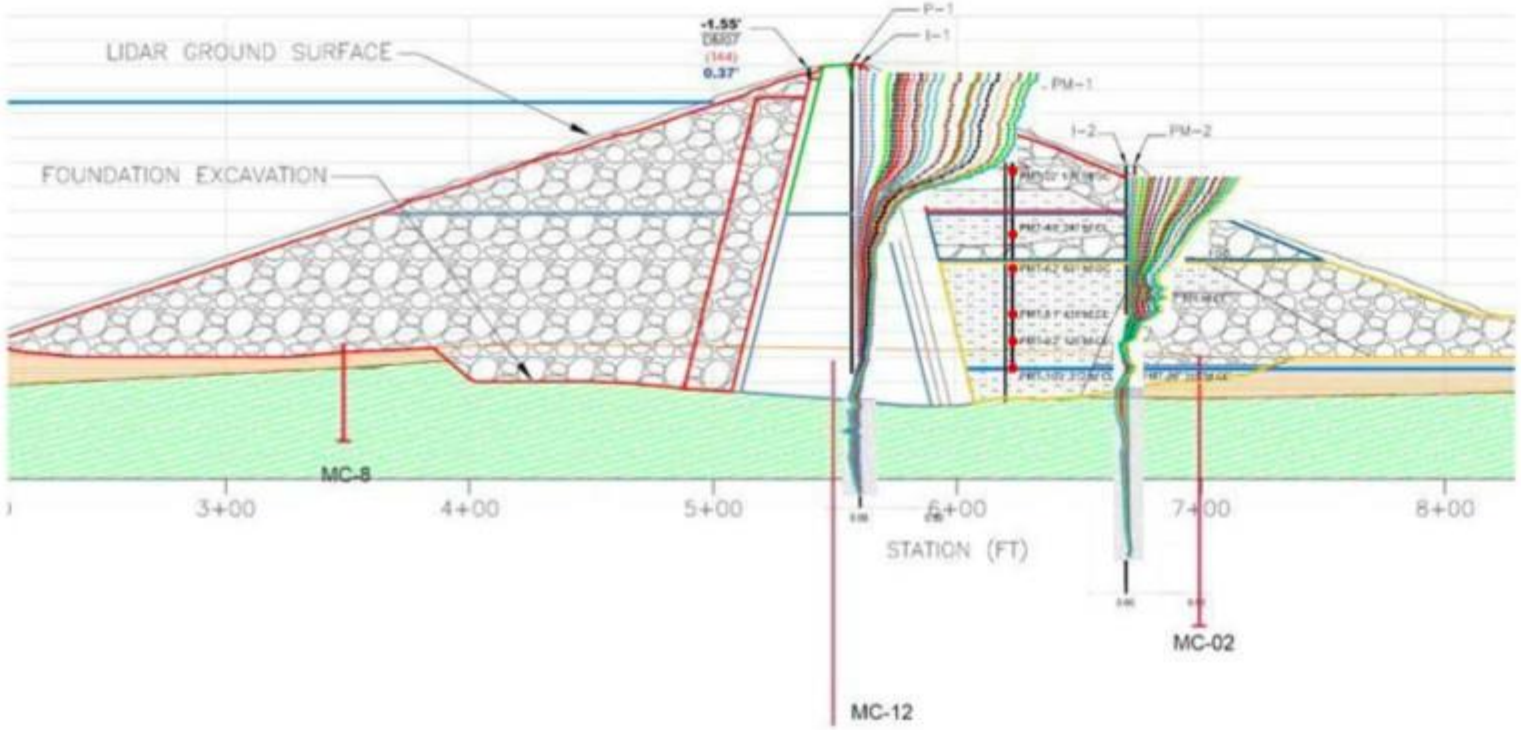
1. Spillway
2. Sandstone
3. Conglomerate
4. Monzonite
5. Sound rock
6. Core trench generalised profile
7. Concrete infills
8. Diversion tunel

A. Crest varies
B. Full supply level
C. Elevation
D. Chainage
E. Instrumented sections
F. Left
G. Right
• Main instrument locations

http://geotip.igt.ethz.ch

Seções Instrumentadas

Cross Section C & Inclinometer Movement



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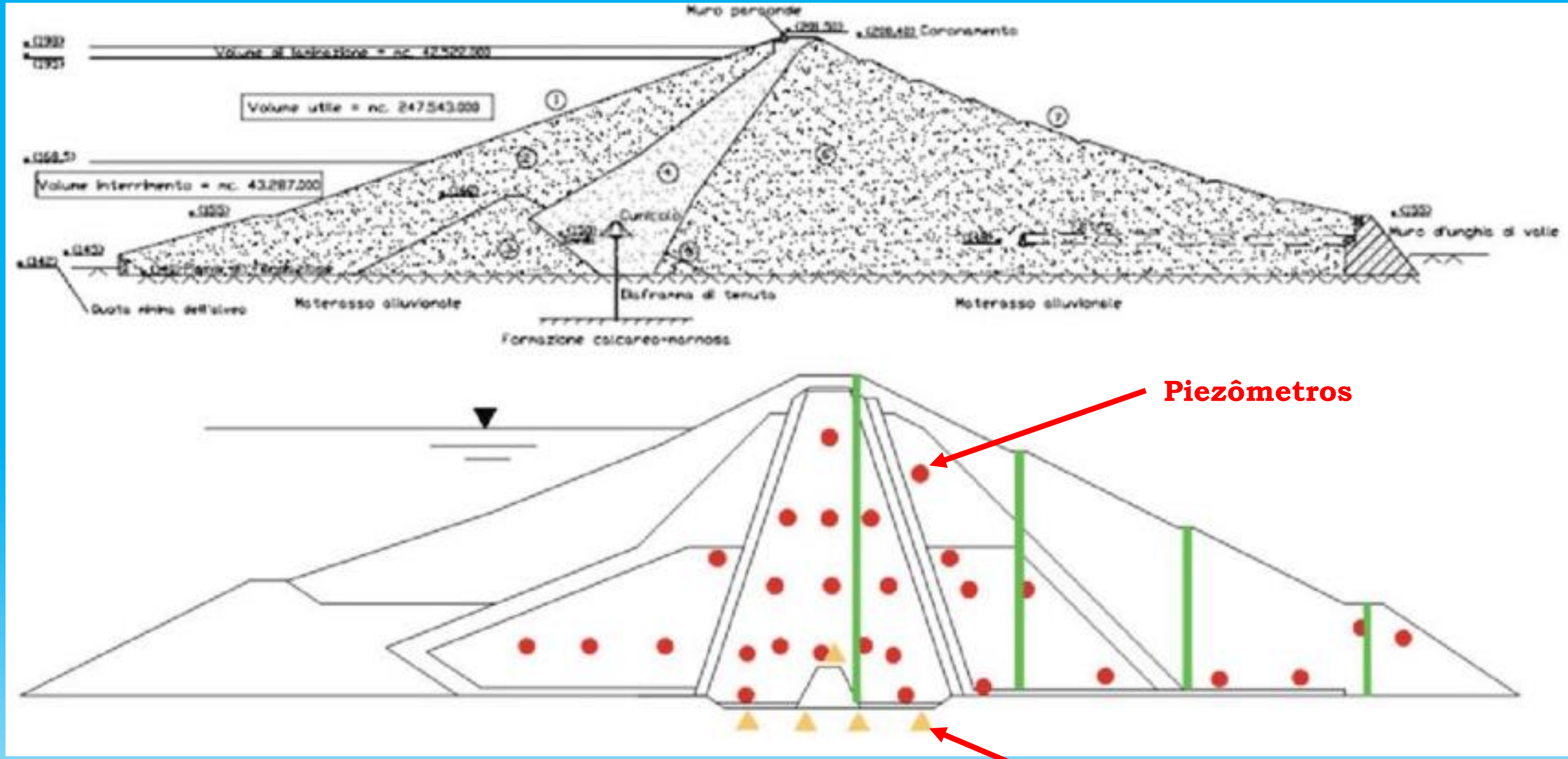

Nico et al (2015)

Monitoramento visual

Rupturas associadas a fluxo que causam erosão interna (pipping) são as mais comuns

Mesmo sem instrumentação os seguintes aspectos devem ser observados:

- Verificar se há evidências de carreamento de material a jusante.
- Verificar se a vazão a jusante aumenta com o tempo.
- Observar se há áreas mais úmidas surgindo em locais antes secos e/ou se estas áreas aumentam.
- Verificar a eventual existência de depressões “sinkholes”.
- Verificar a eventual existência de tricas longitudinais ou transversais.

Alguns aspectos importantes para a segurança podem não ser visualizados, assim o entendimento geral do projeto deve definir um projeto de instrumentação.

Principais requerimentos para acompanhamento de barragens na China (exemplo)

	Concrete Dams	Earth-rockfill Dams
Quantities Monitored	* Foundation subsidence & tilt deflections * Horizontal displacements * Pore water pressure * Seepage * Temperature of concrete * Stresses of the concrete	* Horizontal displacements * Vertical displacements * Pore water pressure * Seepage
Monitoring Accuracy	Horizontal displacement: 1.0 - 1.5 mm Vertical displacement: 1.0 - 1.5 mm	* During construction Horizontal displacement: 10.0 mm Vertical displacement: 5.0 - 10.0 mm * During Operation Horizontal displacement: 5.0 mm Vertical displacement: 3.0 - 5.0 mm
Monitoring Frequency	During Filling of the Reservoir	
	7.0 - 10.0 days	7.0 - 10.0 days
	From Full Filling to Achieving Stability (3 - 5 yrs)	
	0.5 -1.0 month	1.0 month
	During Normal Operations	
	1.0 - 3.0 month	3.0 months

Chrzanowsli et al. (1992)

Frequência da leitura de instrumentos em barragens de terra (exemplo)

Type of Instrument	During Construction		Initial Filling		During Normal Operation	
	Max.	Min.	Max.	Min.	Max.	Min.
Piezometers	Frequently (1/week)	1/month	1/day	1/week	1/week	2/year
Pore Pressure Cells	2/month		1/day	1/week	5/month	1/month
Total Pressure Cells (vibrating wire, pneumatic, other)	1/week	1/month	1/week	2/month	3/month	1/year

Type of Instrument	During Construction		Initial Filling		During Normal Operation	
	Max.	Min.	Max.	Min.	Max.	Min.
Seepage Measure-ments (weirs, flumes,etc.)	1/day	1/month	1/day	1/week	1/day	1/month
Observation Wells	1/2 weeks	2/month	2/week		1/week	1/month
Internal Vertical Movements Devices	frequently	each time a unit is completed	1/week	1/month	3/month	1/6 years
Foundation Settlement	frequently (1/week)	each time a unit is completed	1/day	1/month	2/month	1/year
Internal Settlement Sensors	frequently (1/2 weeks)	1/month	1/week	1/month	2/month	1/year
Inclinometer	frequently (1/2 weeks)	1/2 months	1/week	1/month	6/month	1/year
Extensometer	2/week	1/month	2/week	1/month	3/month	1/2 months
Tiltmeters	1/2 weeks	1/month	1/week	1/month	6/month	4/year
Measurement Points (embankment structural, surface)	1/2 weeks	1/month	2/week	1/month	3/month	1/3 years
Water Quality	1/2 weeks	1/month	1/day	1/month	6/month	2/year
Seismic Activity	continuously		continuously		continuously	
Geodetic Surveys (EDM, Theodolite, etc.)	1/month		1/week	1/month	4/year	1/year
Visual Inspection	1/month		1/day		1/day	1/moth

Notation: 1/day = one or a set of measurements per day.

Avella (1993)

Considerações “finais”

- Não há uma regra geral para o tipo, quantidade e posicionamento da instrumentação. Nem tão pouco procedimento absoluto para o monitoramento visual.
- Nada deve ser desconsiderado antes de uma análise cuidadosa e cruzamento de informações e observações.
- A quantidade de instrumentos e sua localização deve ter em conta os possíveis comportamento da obra, tendo em conta a geologia (local e regional), geotecnia, hidrologia, hidráulica e o projeto proposto e aquele que de fato foi executado (“as built”).
- Os instrumentos devem sempre ser calibrados e aferidos com cuidado, determinando-se sua acurácia.
- Os procedimentos de instalação devem ser cuidadosamente estudados, detalhados e seguidos em todas as instalações.
- A posição de cada instrumento deve ser cuidadosamente conhecida.
- Os dados e informações adquiridas devem ser imediatamente analisadas e as conclusões transmitidas a equipe responsável para eventual providência ou conhecimento.