Risk Analysis, Monitoring and Surveillance: Basic tools in Dam Safety Management

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Chairman: ICOLD Technical Committee on Dam Surveillance
Propósito de la presentación

- Comparto mi experiencia en gestión de la seguridad de presas enfocando:
  - Análisis de riesgos
  - Vigilancia
    - Inspecciones
    - Auscultación
So why risk analyses?

- Severe financial constraints
- Limited or no information
- Human capacity constraints especially from an operational point of view
- Difficulty with appropriate development solutions
- Consideration of failure mechanisms/operational issues not normally considered with standards based approach
Why should there be such a discrepancy between our knowledge and our general practice? To some extent, I fear, because of too much specialization and too little appreciation of the interrelation of the various branches of civil engineering.

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LECCIONES Aprendidas y Nuevas Tendencias
Multi-level risk analysis (levels 0 to 2)

- Level 0 – basic/qualitative
  - Simple probability calculations
  - Sound (experienced) engineering judgement
- Level 2 – detail

Most analyses only Level 0 due to financial & info constraints
Approach

- **STEP 1 - Failure analysis**: Determine probability of dam failure by considering all possible failure mechanisms
- **STEP 2 - Consequence/hazard analysis**: Perform dam break analysis & assess potential losses in event of dam break
- **STEP 3 - Impact and risk assessment**: Evaluate acceptability of combination of impacts & risk
- **STEP 4 - Risk management**: Interpret, make decisions & act on findings of risk assessment
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- % of total failures
- Small dams
- Large dams
- All dams
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Important failure analysis concepts for Level 0

- *No detail fault & event trees*: Due to uncertainties in parameters -
  - Not warranted when applying confidence limits (68%) to data as uncertainties in the data dominate process & little or no significant advantage could be gained

- Practical limit of calculated probabilities of failure is by default $10^{-6}$
  - Failure probability of well-engineered dam with no known deficiencies = $10^{-5}$ to $10^{-6}$ by default

- Extend of failure probability at least 1 order of magnitude due to level of confidence – similar to USBR
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Risk level

- Acceptable
- Unacceptable

Risk of financial losses (R/annum)
Annual risk of fatalities per exposed hour

Risk level
Range of purposes

- Started off as safety evaluations for use in portfolio management
- After more than 30 years of use:
  - **Planning**
    - Highlights for example risk of gated spillways not normally considered during planning – comparing apples with apples
  - **Design**
    - Importance of considering all failure mechanisms
    - Highlighting operational issues
  - **Dam safety evaluations**
  - **Rehabilitation options**
    - Including proper operation & maintenance
  - **DECISION-MAKING on especially O&M issues including proper surveillance**
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Zoeknog Dam failure introduction

<table>
<thead>
<tr>
<th>Background</th>
<th>Basic Statistics</th>
<th>In hindsight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner: Lebowa Homeland Government</td>
<td>Height: 40 m</td>
<td>Dispersiveness tests only done prior to construction and not during construction</td>
</tr>
<tr>
<td>Construction embankment: In-house Lebowa Homeland Government</td>
<td>US slope: 2,5:1 upper part 4,0:1 lower down</td>
<td>AASHTO specifications resulted in drier than optimum PROCTER moisture content</td>
</tr>
<tr>
<td>Construction concrete Grinaker</td>
<td>DS slope: 2,0:1</td>
<td>Homogeneous constructed Blanket drain: 38mm aggregate sandwiched between geotextiles</td>
</tr>
<tr>
<td>Design and site supervision: Eksteen, van der Walt and Nissen</td>
<td>Central clay core: 0,8:1</td>
<td>Geology: Weathered granites</td>
</tr>
</tbody>
</table>
In hindsight (2)

Piezometers installed by Fil Filmalter (Kop-Kop) Latter discovered that blanket drain (left of outlet tunnel) not on founding level but 5m higher (indicated as founding level on drawings
Several warnings on OMC: Filmalter and DWA officials, (unofficially) pointed dubious OMC out

Piezometer warning:

Impoundment started towards end of 1992
Filmalter warned that one of the piezometers installed on the left-hand side of the outlet conduit is recording high pressures

Piezometer warning ignored 10 Jan 1993

Zoeknog Dam failure timeline
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Fig. 1 (1-1)
Cross section of embankment adjacent to conduit

NOTATION
A- INTAKE TOWER
B- MORNING GLORY SPILLWAY
C- CHIMNEY DRAIN
D- CONDUIT
E- BLANKET DRAIN
F- STONE DRAIN
G- EMBANKMENT FILL
H- FOUNDATION LEVEL
I- TRENCH FILLING
J- TRAINING WALL
K- ROCK EXCAVATION FACE
L- ROCKFILL CONE
M- SPILLWAY SHAFT

Fig. 2 (2-2)
In hindsight (2)

Piezometers installed by Fil Filmalter (Kop-Kop) Latter discovered that blanket drain (left of outlet tunnel) not on founding level but 5m higher (indicated as founding level on drawings)

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Piezometer warning:

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Zoeknog Dam failure timeline

Jan 25 1993: Dam failure early morning hours
Soon after midnight guard heard water running ... Progressed from piping to dam empty in 6 hours. No lives lost

Feb 2 & 4 Dam safety
First investigations:

Feb 12 Another investigation
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In a perfect world with a proper design, construction and operation.

Risk level

Risk of financial losses (R/annum)
Annual risk of fatalities per exposed hour

1.0E-11 1.0E-10 1.0E-09 1.0E-08 1.0E-07 1.0E-06
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Risk of financial losses (R/annum)
Annual risk of fatalities per exposed hour
Risk level

Risk of financial losses (R/annum)
Annual risk of fatalities per exposed hour
Risk level
React to piezometer warning during construction

Risk of financial losses (R/annum)

Annual risk of fatalities per exposed hour

Risk level

19/10/2017
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The reality

Risk level

Risk of financial losses (R/annum)
Annual risk of fatalities per exposed hour

19/10/2017
How important is visual inspections?
There is no substitute for systematic and intelligent surveillance

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19/10/2017

Sink hole
Current situation

Risk level

19/10/2017
Without the visual inspection results

Risk level

Annual risk of fatalities per exposed hour

Risk of financial losses (R/annum)
Intervention process

- Detail investigation to determine failure mechanism
  - How long have this sink hole been here?
  - Is there any other sinkholes?
  - What caused this sinkhole?
- Consider all possible interventions including costing
- Determine most appropriate by considering the unit risk reduction cost
There is no substitute for systematic and intelligent surveillance

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Value of visual inspections
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Theoretical institutional memory

construction
design
impounding
operation
floods
additional works

Living memory

Knowledge

Time (Years)

WITHOUT VISUAL INSPECTIONS
What is the lifespan of a dam?
THE CORPORATION OF THE CITY OF CAPE TOWN
THIS THE LAST STONE OF THE DAM WAS LAID BY
HIS WORSHIP THE MAYOR
SIR JOHN WOODHEAD, J.P.
ON
THE FIRST DAY OF MAY 1897
BEING THE YEAR OF THE DIAMOND JUBILEE OF
HER MOST EXCELLENT MAJESTY QUEEN VICTORIA.
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Additional works
Documentation
Theoretical institutional memory
Construction
Design
Impounding
Operation
Floods
Additional works
Living memory
Theoretical memory
Knowledge
Time (Years)

WITHOUT VISUAL INSPECTIONS
Visual inspection programs
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Programa de Inspección Última

**Level 5**
Performed continuously by dam operator

**Level 4**
Performed monthly by dam operator supervisor

**Level 3**
Performed quarterly by technician

**Level 2**
Performed annually by engineer

**Level 1**
Performed 5-yearly by professional team
Inspection program for smaller dams

- **Level 5**: Performed continuously by dam operator.
- **Level 4**: Performed monthly by dam operator supervisor.
- **Level 3**: Performed quarterly by Dam operator.
- **Level 2**: Performed annually by engineer.
- **Level 1**: Performed 5-yearly by professional team.

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Typical requirements

- **Level 1 – Operator & Level 2 - Supervisors:**
  - diligence
  - dam safety experience (especially of the particular dam)
  - a positive attitude
  - definitely not a high level of education
  - supervisors should ideally have progressed through ranks

- **Level 3 & 4:**
  - due diligence of utmost importance
  - relevant qualifications but diligent and intelligent individuals have progressed by means of appropriate experience & self-education
Failure factors

- Lack of will by decision-makers even though it is low cost
- Inappropriate levels of education and experience requirements & lack of refresher courses
  - Over-qualified/under experienced
  - Under qualified/under experienced
- Lack of recognition for value of routine visual inspections. Effectiveness of applying Hawthorne effect (a form of reactivity whereby subjects’ show an increase in productivity due to the motivational effect of interest shown in them)
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Concluding remarks

- Risk analyses
  - Over lifespan of dam
  - Quantify operational risks
  - Consider all potential failure mechanisms
  - Improve decision-making especially with Operation & Maintenance
  - Optimise technical decisions
Concluding remarks

- Visual inspections essential for development & accumulation institutional memory
- Plays important role in evaluation of dam behaviour
- Proper implementation of effective & successful visual inspection programme depends on:
  - properly designed formal process
  - appointment of appropriate personnel (diligent with the appropriate levels of experience & education for each of the levels of responsibility)
- Long-term success by applying the Hawthorne effect
Acknowledgements

- Dr Chris Oosthuizen
- All whom in some way or other contributed along the way
- Last but definitely not least – SPANCOLD invite
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Thank you