DAM SAFETY AND RISK ANALYSIS
BENCHMARKING
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PRESENTATION OUTLINE

1. INTRODUCTION TO BENCHMARKING
2. THREE-DIMENSIONAL ABUTMENT STABILITY OF DAMS UNDER STATIC AND SEISMIC LOADING SAFETY AND SEISMIC VERIFICATION DAMS
3. SEISMIC SAFETY EVALUATION OF A CONCRETE DAM BASED ON GUIDELINES
4. BENCHMARK RISK ANALYSES - OVERVIEW
5. BENCHMARK RISK ANALYSES - RESULTS
6. CONCLUSIONS
INTRODUCTION

- Benchmarks within the context of dam engineering consist of formulating a problem statement with a unique set of data (geometric, material parameters, loads, boundary conditions, etc.) and requesting the participants to produce a unique set of problem results that may be compared and critically analyzed.

- Benchmarks provide industry with real-life example reference solutions that may be used for software validation, training and project applications.

- Benchmark strategies can be applied in dam safety analyses either within a deterministic (safety pillars) and/or probabilistic (Potential Failure Mode, PFMA or Quantitative Risk Analyses, QRA) context.
INTRODUCTION – BENCHMARK SUMMARY 1991-2016
THEME CONTRIBUTIONS

Countries

Themes
INTRODUCTION – BENCHMARK SUMMARY 1991-2016

SUBJECTS

23rd & 24th January, 2018, Thiruvananthapuram, Kerala, India

International Dam Safety Conference – 2018
Technical Session 3B, Dam Safety Management and Practices

Seismic; 21%

Thermal; 13%

Static; 10%

Strength; 2%

Uplift; 2%

Safety; 8%

Seepage; 5%

RCC; 0%

Rapid drawdown; 1%

Probabilistic; 1%

Phased Analyses; 2%

Open; 12%

First-filling; 4%

Flooding; 1%

Design; 1%

Interpretation; 3%

Abutment stability; 1%

AAR; 4%
INTRODUCTION – BENCHMARK SUMMARY 1991-2016

REFERENCES
THREE-DIMENSIONAL ABUTMENT STABILITY OF DAMS UNDER STATIC AND SEISMIC LOADING – PROBLEM STATEMENT
THREE-DIMENSIONAL ABUTMENT STABILITY OF DAMS UNDER STATIC AND SEISMIC LOADING – PROBLEM STATEMENT

Objectives

- Deliberate on design criteria and methodology for static and seismic analyses for wedge abutment stability problems (Newmark method).
- Compute the wedge forces, displacements and factors of safety.
- Demonstrate how state-of-the-art computational aspects of analysis and design of dams can be applied to the problem.
- To perform sensitivity analyses to define the limitations of the problem.

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THREE-DIMENSIONAL ABUTMENT STABILITY OF DAMS UNDER STATIC AND SEISMIC LOADING – RESULTS AND CONCLUSIONS

- **Problem results (highlights)**
  - Ambiguous approach to the definition of sliding **plane uplift pressures**
  - Critical **multi-directional** seismic loading not systematically performed
  - Common approach to analysis methods (Londe, Newmark)
  - Review of participant results provided **plausibility concepts** that could be applied in post-dynamic dam abutment safety analyses valid for subsequent PFMA and QRA studies

- **Conclusions**
  - Importance of **data reliability**
  - **Approach** to numerical studies
  - Evaluation of results by **well qualified and experienced professionals**
  - **Sensitivity** and screening studies, QRA and the implementation of residual risk measures can be realistically integrated into a Dam Safety Implementation Plan (DSIP)
SEISMIC SAFETY EVALUATION OF A CONCRETE DAM BASED ON GUIDELINES – PROBLEM STATEMENT

Overview

✓ Total of 206 Large Swiss Dams have been specifically verified for seismic loading using Swiss Directives between 2000-2016
✓ These studies have enabled a considerable amount of experience and knowledge to be acquired not only for seismic verifications, but also for the ageing of these structures, remedial measures, rehabilitation works (if required) and a more general contribution to safety evaluations and the associated risks

Problem Motivation

✓ Appropriateness of current state-of-the-art numerical tools to satisfy the requirements of International and National Directives/Guidelines.
✓ Capabilities of current state-of-art numerical tools to solve complex Dam Engineering problems beyond Directives/Guidelines.
✓ Compatibility between the “Tools” and the “Directives/Guidelines” in terms of methods, results, and post-processing techniques needed for plausibility checks and engineering evaluations, interpretations.
✓ Qualitative and quantitative precision of the “Tools” to predict the real behaviour of the structure (dam, foundation, appurtenant works) subjected to complex loading/restraint conditions
SEISMIC SAFETY EVALUATION OF A CONCRETE DAM BASED ON GUIDELINES – PROBLEM STATEMENT

Self-weight (Phased)  FSI – IC/C

Thermal (Summer)

Massless Foundation

3 sets (x, y, z) earthquake TH/Spectra

FE Mesh Data (Rock, Dam, Reservoir)

Load case combinations

Sections @ Centre, X2 Left, X3 Right

<table>
<thead>
<tr>
<th>Load combinations</th>
<th>Static</th>
<th>su0</th>
<th>su2</th>
<th>DE2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-weight</td>
<td>1</td>
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<tr>
<td>Hydrostatic pressure (El. 1606 m a.s.l.)</td>
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<td>1</td>
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<tr>
<td>Silt pressure</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Temperature gradients</td>
<td>Summer</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Earthquake</td>
<td></td>
<td>Series 1</td>
<td>1</td>
<td>1</td>
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<td></td>
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<td>Series 3</td>
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</tr>
</tbody>
</table>
SEISMIC SAFETY EVALUATION OF A CONCRETE DAM BASED ON GUIDELINES – PROBLEM STATEMENT

Rocking/sliding Block Crown Section
Stability at different heights (X/H : 0.04, 0.08, 0.14, 0.20) – Fully open joints, cohesionless cracked section
SEISMIC SAFETY EVALUATION OF A CONCRETE DAM BASED ON GUIDELINES – PROBLEM RESULTS

Mode shapes – Good comparison between results, however, some variation between the dominant masses and directions exists.
Problem results (highlights)

- No unique solution: Considerable variation of computed displacements, stresses and Factor of Safety.
- The methods employed ranged from free-body diagrams to the use of non-linear interaction elements (NLFEM).
- For this particular problem statement, it becomes again evident that PFMA and QRA studies must be carefully evaluated.
- The ability to identify the main sources of failure and how to make a quantitative assessment is critical in risk analyses.
BENCHMARK RISK ANALYSES

Benchmark Valencia 2011
Sliding failure probability in concrete dam

Benchmark Lausanne 2015
Instability failure probability in embankment

Benchmark Graz 2013
Consequence estimation of dam failure

Benchmark Stockholm 2017
Sliding failure probability in concrete dam
# BENCHMARK 2015 - RESULTS

<table>
<thead>
<tr>
<th>Reference</th>
<th>Slope Instability Model</th>
<th>Number of simulations</th>
<th>Random variables</th>
<th>Main uncertainties detected</th>
</tr>
</thead>
</table>
| Solution  | Modified Bishop's Method| 10,000                | Friction angle   | - High dependence of resistant parameters.  
|           |                         |                       | Cohesion          | - Phreatic level hypothesis.  
|           |                         |                       |                  | - Considerations for specific weight of soil.  
| Andreev and Zhelyazkov | Morgenstern and Price (SLOPE/W) | 5,000 | Friction angle   | - Seepage process through the embankment during heavy rains.  
|           |                         |                       | Cohesion          | - Soil properties.  
|           |                         |                       |                  | - Shear strength in unsaturated soil.  
| Wilde and Varquez | Morgenstern and Price (SLOPE/W) | 2,000 | Friction angle   | - Pore water pressure.  
|           |                         |                       | Cohesion          | - Effective strength parameters. Correlation between them.  
|           |                         |                       |                  | - Shear strength for unsaturated soils.  
|           |                         |                       |                  | - Young Modulus and Poisson's ratio.  
| Moyeaux et al. | Morgenstern and Price (Geostudio) - Steady state | 1,000 | Friction angle   | - Hydraulic conditions: Steady state or transient.  
|           |                         |                       | Cohesion          | - Mechanical parameters.  
|           | 3. Finite Element Model (Cast3M) - Steady state | 10,000 (Response Surface) | Friction angle |                  |  
|           | 4. Finite Element Model (Cast3M) - Transient |                       | Cohesion          |                  |  

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BENCHMARK 2015: RESULTS

- Reference solution
- Andreev and Zhelyazkov
- Wilde and Vazquez
- Case 1
- Case 2 Moyeaux et al.
- Case 3
- Case 4

Conditional failure probability vs. Water level in the reservoir (m)
CONCLUSIONS

- Last advances in computational methods have allowed a higher development of risk analysis techniques, from simple structural models to complex numerical procedures and methods.

- Significant differences in results in the four Benchmarks.

- Risk analysis has demonstrated to be a useful tool to analyze the impact of the hypotheses that engineers assume in normal dam safety practice and that are often overlooked. For instance:
  - Numerical models equations.
  - Geotechnical parameters distributions.
  - Dam failure breach parameters.
  - Hydraulic models parameters and equations.

- More info in Conference paper and Benchmarks proceedings.
Thank you for your attention

“We cannot solve our problems with the same thinking we used when we created them,” Albert Einstein