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Rock Engineering and Dam Safety: Building Stronger Partnership

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Abstract

Europe is home to over 8200 large dams currently registered in Europe, which constitute a strategic infrastructure for hydro power production, water supply, irrigation, flood protection and climate resilience. However, this infrastructure is facing increasing challenges associated with ageing dams, extreme hydro logical events, climate change, higher safety requirements and the need to extend the operational life of existing dams

Engineering plays a fundamental role in ensuring the safety, reliability and long term performance of dams and their associated infrastructure. Rock Engineering should be considered as essential component throughout the entire life cycle of a dam. The behaviour of rock foundation, abutment, slopes and underground structures directly influences the structural integrity and operational safety of dams throughout their service life.

Increasing challenges related to climate change, extreme hydro logical events, ageing dam infrastructure and growing environmental expectation require innovative engineering solutions supported by strong interdisciplinary cooperation.

The paper highlights the importance of dam foundations and engineering monitoring as key elements of dam safety management. Modern geological, geotechnical and hydro geological technologies together with advanced instrumentation, remote sensing and digital monitoring systems are presented as essential tools for the early detection of potential problems, risk assessment and informed decision-making.

Finally, the presentation emphasizes the importance of establishing a strong strategic partnership between EURCOLD and ISRM. Such cooperation would strengthen the exchange of technical knowledge, promote joint research and innovation, and support professional training and capacity building.

Strengthening this partnership will contribute to safer, more resilient and more sustainable dams in Europe.

Keywords

Large dam, Dam Safety and Monitoring, EURCOLD, ISRM, Rock Engineering.

1 Introduction

According to the ICOLD world register, Europe has approximately 35 000 dam, storing more than 1500 billion m^3 of water. Among them, 8240 are classified as large dams with height more than 15 m.

38 European countries have built dams and 32 countries are members of ICOLD (fig.1).

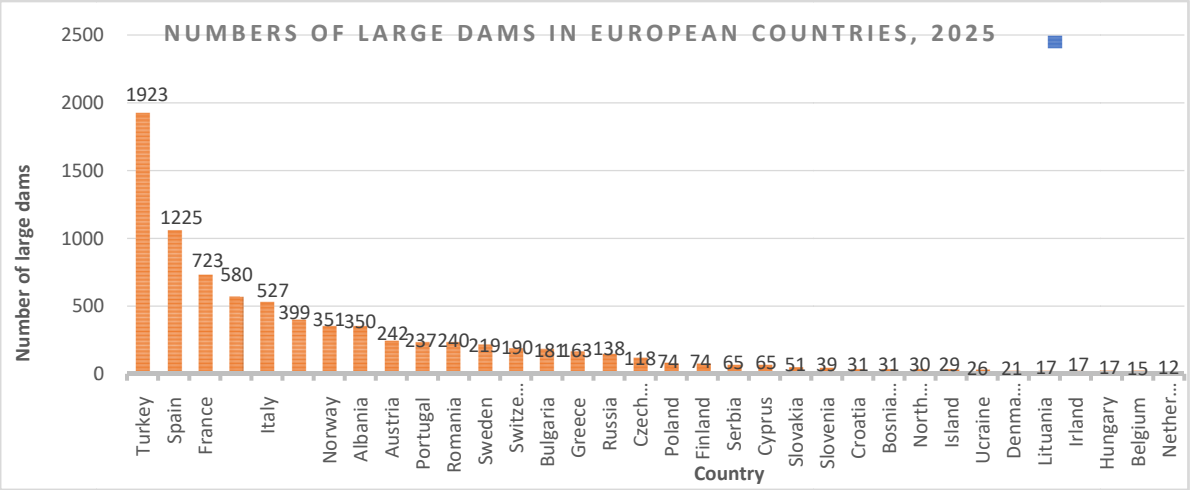


Fig. 1 Numbers of Large Dams in European countries, 2025.

The dams are very important strategic infrastructure. Their role is very important for

- ✓ Hydropower Production
- ✓ Water Supply
- ✓ Irrigation and Fishing
- ✓ Flood protection
- ✓ Transport and Urban Attraction

Europe is currently facing major challenges related to

- ➢ Dam Safety
- ➢ Climate change
- ➢ Flood protection
- ➢ Modernization of aging infrastructure
- ➢ Renewable energy production

At the same time, the dam sector in Europe is experiencing increasing pressure related to

- ➢ Aging Infrastructure
- ➢ Financial limitation for rehabilitation projects
- ➢ Environmental and social requirements
- ➢ Public perception and communication challenges
- ➢ Need for highly qualified young professional in the sector

EURCOLD is a ICOLD regional club that is established in 1995. It is one of the largest regional club within ICOLD. Main focus of EURCOLD is

- Support and Promote of existing EWGs and Encourage the formation of New EWG (EWG on Dam Promotion and EWG on Dam Legislation and EU Policies).
- Close Cooperation with European NC, Support and promotion of the Dam safety activities.
- Collaboration with other main actors in Dam engineering sector and support related research project.
- Promote Young Professional's engineers in EURCOLD activities.
- Raise Public Awareness & Acceptance on Dams.
- Organization of the Dams and Reservoir day 2026.

2 The Role of Rock Engineering throughout the dam life cycle

Rock engineering plays a fundamental role throughout the entire life cycle of a dam, providing the geological and geotechnical basis required to ensure its safety, performance and long-term sustainability.

Its contribution begins long before construction starts and continues until the dam reaches the end of its service life and where necessary, is decommissioned.

The first and most critical stage is the **site investigation**, where engineering geological mapping, remote sensing, drilling, in situ testing, laboratory investigations and hydro-geological studies are carried out to characterize the rock mass and identify potential geological hazard. These investigation provide the information required for selecting the most suitable dam site and for the assessing the feasibility of the project.

During the **design phase**, rock engineering support the development of safe and efficient engineering solutions by evaluating foundation conditions, slope stability, abutment behaviour, underground excavations, seepage conditions and the mechanical properties of the rock mass.

Numerical modelling and geotechnical analyses are increasingly used to optimize the design and reduce geological uncertainties.

Throughout the **construction phase**, engineering geologist and rock engineers play a key role in supervising excavations, verifying geological conditions, adapting designs to field observations and implementing foundation treatment measures such as grouting, drainage systems, rock reinforcement and stabilization works. Continuous geological assessment during the construction is essential because actual ground conditions may differ from those identified during the investigation stage.

Once the dam becomes operational **engineering monitoring** becomes one of the most important components of dam safety management. Rock engineering contributes to interpreting the behaviour of foundations, abutment and surrounding slopes through geological, geotechnical and hydro-geological monitoring. Modern monitoring technologies, including remote sensing, satellite observation, UAV surveys, LiDAR, fibre-optic sensors and digital monitoring systems, allow engineers to detect changes at an early stage and support informed decision making.

As dams age, rock engineering also plays a central role in **periodic safety assessment**, rehabilitation and life-extension projects.

Re-evaluation of geological conditions, foundation performance, seepage behaviour and slope stability enables dam owners to identify emerging risks and implement appropriate remedial measures that ensure continued safe operation.

Throughout every stage - from the initial geological investigations to decommissioning - rock engineering remains an essential discipline that support informed engineering decisions, minimize geological risks and contributes significantly to the safety, resilience and sustainability of dam infrastructure.

3 Dam Monitoring as a Key element of Dam Safety

Dam monitoring is one of the fundamental pillars of dam safety management, providing continuous information on the structural behaviour of the dam, its foundation, abutment and surrounding geological environment. Monitoring enables engineers to verify design assumptions, assess the performance of the structure under different loading conditions and detect anomalies before they develop into safety - critical problems. An effective monitoring programme is therefore essential throughout the entire operational life of a dam.

Traditional monitoring systems have been successfully used for decades and continue to play an important role in dam safety. These systems include piezometers for measuring pore water pressure, uplift pressure gauges, seepage measurement devices, pendulums, extensometers, joint meters, inclinometers, settlement markers and other geotechnical and structural instruments. Together, they provide valuable information on deformation, seepage, stress distribution and the overall response of the dam and its foundation.

However, the increasing complexity of dam safety challenges, together with aging infrastructure and impacts of climate change, requires a new generation of monitoring systems capable of providing continuous, high-resolution and real time information. Modern dam safety management should integrate conventional instrumentation with advanced digital technologies to improve the reliability and efficiency of engineering assessments.

Among the most promising technologies are fiber-optic sensing systems, which enable continuous monitoring of strain, temperature and deformation over long distance with high accuracy.

Satellite-based Interferometric Synthetic Aperture Radar (InSAR) has become an effective tool for detecting millimeter- scale ground and structural displacement over large areas, allowing engineers to identify long-term deformations trends.

LiDAR technology provides highly accurate three-dimensional model of dam structure, slopes and surrounding terrain, supporting detailed geological mapping, stability assessment and change detection. In addition, Unmanned Aerial Vehicles (UAVs) equipped with high-resolution cameras and laser scanners significantly improve the inspection of inaccessible areas and facilitate rapid post-event assessments.

The integration of Artificial Intelligence (AI) and machine learning into dam monitoring represents another major step forward, AI can analyze large volumes of monitoring data, identify hidden patterns, detect anomalies at an early stage and support predictive maintenance and risk-informed decision making. Combined with digital twins and cloud-based data management systems, these technologies enable the transition from periodic inspections to intelligent, continuous and predictive monitoring.

The future of dam safety depends on the integration of engineering with advanced monitoring technologies. Modern monitoring systems not only improve the understanding of dam behaviour but also enhance early warning capabilities, optimize maintenance strategies and strengthen the resilience and long-term safety of dam infrastructure.

As such, monitoring should be regarded not simply as an operational requirement but as a strategic investment in the sustainable management of dams and reservoirs.

4 Why a Strong Partnership Matters

The challenges facing today's dam sector require stronger collaboration between organizations with complementary expertise. In this context, a strategic partnership between the EURCOLD and ISRM can make a significant contribution to improving dam safety and promoting engineering excellence.

EURCOLD and ISRM share common objectives, including the advancement of technical knowledge, the promotion of innovation, the dissemination of best engineering practices and the development of highly qualified professionals. While EURCOLD focuses on the safety, operation and sustainable management of dams and reservoirs, ISRM provides internationally recognized expertise in rock mechanics and rock engineering, which forms the foundation of safe dam design and performance.

Dam safety starts with a thorough understanding of the rock mass. The geological conditions of the foundation, abutment and surrounding slopes directly influence the behaviour of a dam throughout its entire life cycle. Comprehensive geological investigation and sound rock engineering are therefore essential for reducing uncertainty, minimizing risk and ensuring the long-term stability of dam infrastructure.

Strong cooperation between EURCOLD and ISRM will create better engineering solutions by combining expertise from both organizations. Joint technical activities, research projects, conferences, training programs and technical guidance will promote multidisciplinary approached and encourage the application of innovative technologies to address emerging challenges such as climate change, ageing infrastructure and increasing safety requirements.

Equally important is the continuous exchange of international knowledge and experience. Through collaboration between experts, universities, research institutions and young professionals, both organizations can accelerate the transfer of best practices, strengthen technical capacity and support the development of safer and more resilient dams.

A stronger EURCOLD-ISRM partnership is therefore not only beneficial for both organizations, but also an important investment in the future of dam safety and sustainable infrastructure.

5 The Future Cooperation between EURCOLD and ISRM

The future of dam safety will increasingly depend on strong partnerships that combine knowledge, experience and innovation across different engineering disciplines. The challenges of climate change, ageing infrastructure, increasing safety expectations and rapid technological development cannot be addressed by a single profession or organization alone. They require multidisciplinary cooperation and a shared commitment to engineering excellence.

The partnership between EURCOLD and ISRM provides a unique opportunity to bring together the expertise of dam engineers and rock engineers under a **common vision: to improve the safety, resilience and sustainability of dams and their associated infrastructure**.

There is a simple but powerful principle that should guide this cooperation: **Unity creates strength, strength creates safety**.

By bringing together the experience of dam engineers and rock engineers, both organization can strengthen technical knowledge, promote innovation and support the application of modern engineering practices throughout the entire life cycle of dams. Joint technical committees, research initiative, conferences, professional trainings and the exchange of international experience will contribute to safer, more resilient and more sustainable dam infrastructure.

Particular attention is not only about two organizations working together-it is about creating a stronger engineering community capable of addressing future challenges.

6 The Conclusion

Together, EURCOLD and ISRM can transform a shared vision into concrete action. By combining the expertise, we can improve the safety, resilience and sustainability of dams and their infrastructure.

Rock Engineers and Dam Engineers built stronger foundations, stronger partnership and safer dams with vision to improve the safety, resilience and sustainability of dams and their associated infrastructure and Principe: **Unity creates strength, strength creates safety.**

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